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# SILICON CHIP

FEBRUARY 2015
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**WITH SOFT START**

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- PCB: 85 x 46mm

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# Publisher's Letter

## Electronics affects every area of society – why not debate it?

My Publisher's Letters are often controversial, and often trigger angry responses. Some readers send in angry emails while others go to web forums where their comments can be quite, let me just say, "unbalanced". Some readers also attempt to curtail and sanction my editorials with the threat of refusing to buy any more SILICON CHIP magazines. Some have done just that.

I accept that some readers will not agree with some of my editorials. I don't agree with some of the editorials in my daily newspaper but if that happens I just turn the page. I don't fire off an angry email or consider cancelling future newspaper deliveries – that would merely be "cutting off my nose to spite my face".

However, I cannot understand why the topics discussed should cause so many people to say that they should not be in the magazine at all. Why not discuss climate change, wind power, nuclear power and host of other topics in which electronics and technology have an all-pervasive effect? Surely, that is valid.

A few years ago, I attended a lecture by a prominent climate scientist from the University of New South Wales, hosted by the IEEE. After the lecture there was heated comment, both in favour of and against some of the predictions by the climate scientist. Clearly, the engineers felt able and justified to question and probe the various predictions, some of which may never come to pass, in spite of being passionately promoted by the climate scientist. So if the engineers were comfortable and indeed passionate about issues such as this, why not discuss them in SILICON CHIP?

So why not have an article about the possible medical effects of wind turbines and an accompanying Publisher's Letter on the topic? Why not have a project to measure the ultrasonic signals from wind turbines? So we did. And why not discuss nuclear power? It is just another way of generating electricity and its merits and drawbacks are quite relevant to a magazine like SILICON CHIP, just as solar power is relevant.

And when we published the article on Argus, surely a legitimate technical topic in SILICON CHIP (December 2014), why not have a Publisher's Letter discussing how it could be used to fight crime, as it surely will? Will all-pervasive surveillance systems have significant privacy issues? Of course they will, just as do octocopters and much of the technology being used in unmanned vehicles, a major feature article in this month's issue.

The point is that virtually every aspect of electronics has significant effects on society and they should be discussed. Furthermore, every technical innovation will have a possibly unseen and unwelcome effect. Nobody would deny that smartphones are wonderful but they also present a vast range of unwelcome effects on individuals and society in general.

These effects of electronics technology should be discussed. And where else but in one of the very few electronics magazines in the world?

To try to shut down such discussion is yet another attack on free speech. We all know where that can ultimately lead.

**Leo Simpson**

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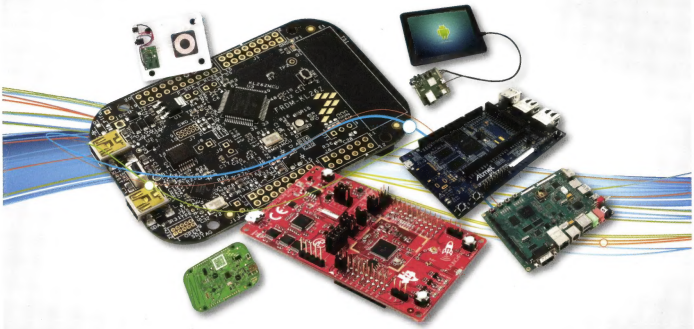

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# MAILBAG

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### Currawong amplifier is a good contemporary design

Congratulations to the team at SILICON CHIP for having the courage to publish a modern design for a valve audio power amplifier. While I do not intend to construct it, the pleasure has been in reading how modern components can be selected and adapted to achieve a contemporary design that is easy and economical to build.

The project was a real education for me in what can be achieved using valves with today's components and construction methods.

**Ted Linney,**
**Wellington, NZ.**

### Appreciation for hearing aid articles

Thanks for SILICON CHIP's various articles about hearing aids at a reasonable price (Blamey and Saunders; Hearing Australia). It's important that this sort of thing is brought to the public's attention.

While digital hearing aids certainly are a wonder of modern science, administered by highly-trained professionals, this is no reason for the public to abandon scrutiny of those practising such science, thereby allowing the few unscrupulous in their ranks to prescribe exorbitantly expensive devices.

The matter of "fair price" and "fair go" is very topical it seems. Recently, the ABC program "Background Briefing" had an excellent report making us all aware off how audiologists are under pressure to "sell" and push product, apparently with the interests of the customer well down the list of concerns.

Thanks once again for "more than an electronics magazine"!

**Aubrey McKibben,**
**Swan Hill, Vic.**

### The coming radio wave of digital encrypted sounds

I recently purchased a Uniden UBC355XLT radio scanner, hoping to have some radio scanner fun, as I remember the good old 27MHz CB days back when the VHF and UHF bands buzzed with police and business 2-way traffic. At that time, radio had lots of good things, like baby monitors left on and cordless phones giving the neighbourhood gossip.

My new radio scanner worked great for the 130MHz air-band, 477MHz UHF CB, some odd 2-metre transmissions and 147MHz repeaters. The old 27MHz CB band is mostly silent now. There are still some SSB old-timers down on the 80-metre & 40-metre amateur bands but 10-metres is very quiet. Also silent is most of the VHF low band, baby monitors, ambulances etc.

But also just very recently came the bad news that all 2-way radio is slowly moving to 100% digital. Not just the police that are now 100% encrypted digital but also the digital and part analog, half-receivable Motorola trunked radio systems now used by ambulances, bus, fire, rail and other government departments. So an all-new $400 triple trunking radio scanner may not work at all.

But the largest shock is that the much beloved Amateur Radio is also moving to digital too, with D-STAR a now all-digital system by Icom and others like Kenwood & Uniden. As many of the new all-digital formats are copyrighted, only the one brand or code of radios can receive them.

If your local agencies encrypt their digital signals, which nearly all of them will do in time when sold the next-generation of all-digital radios, there won't be a consumer radio you can buy to listen to them. So copyrighted and encrypted digital transmissions has effectively killed the radio scanner hobby. Even good old HF SSB is moving to D-STAR, so in time this may also

### Petrol mowers still have their place

The Publisher's Letter in the January 2015 issue makes a very valid point that electric lawn mowers and other electric garden tools do have a place in suburbia. In fact, a friend of mine has an electric chainsaw but unlike an electric lawnmower, I did need ear muffs when using it, because it was still quite noisy. It was very handy when we lopped some trees in his back yard and substantially quieter than my petrol-powered chainsaw.

Electric lawn mowers are fine if you can keep your grass short and mow regularly. When we get a lot of wet weather in summer, I can't mow my lawn for several weeks and the grass gets quite long and thick. It's a real struggle for my 4-stroke mower to get through this and I have to empty the catcher every few metres. You'd never cut that with an electric or battery-powered lawn mower.

So petrol power tools do have their place in certain situations and they are the only practical thing to use when you aren't near a power point or you need that extra power for a tough job.

I'm glad to see a "beginners'" kit in the magazine (the PicoMiniCube) but it's something you can't build from scratch, due to the copyright on the design. It would be good to have more simple projects in the magazine for beginners and less experienced constructors and those who like to make their own (simple single-layer) PCBs. I hope we can see more projects like the RC substitution boxes (April 2012 and August 2014) that actually have a practical use when finished.

**Bruce Pierson,**
**Dundathu, Qld.**

# Your question:
# What does the R&S®RTO have to offer at 4 GHz bandwidth?

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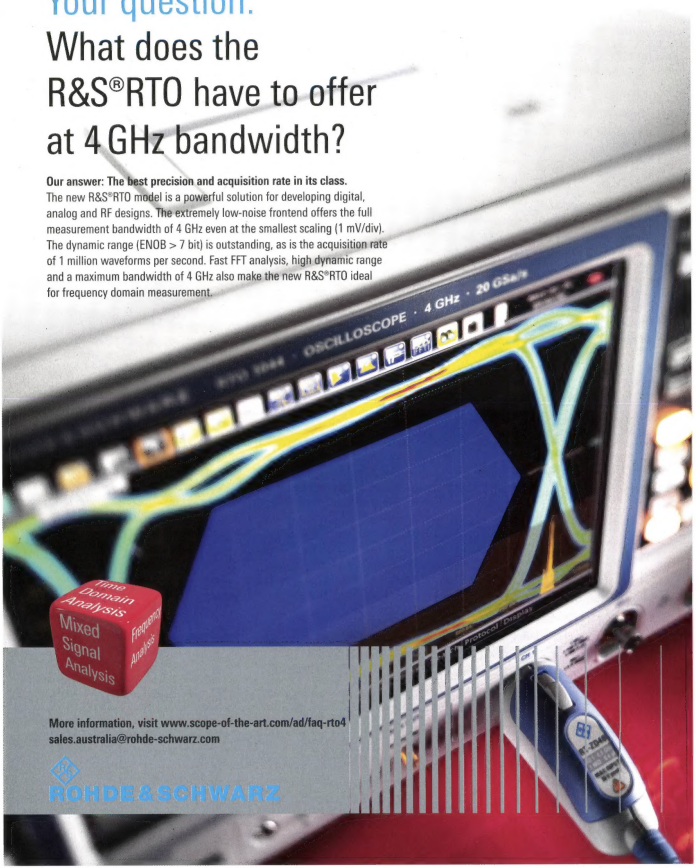


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## Mailbag: continued

### Induction Motor Speed Controller gives excellent results

After some trial and tribulation to find and correct a mistake in assembly, I can report that I have connected the Induction Motor Speed Controller to my milling machine and it works perfectly, to provide low and high speed with forward and reverse. I was quoted about six thousand dollars to have 3-phase power installed to the house but this project solution cost about $240!

The unit is a Universal Toolmakers milling machine manufactured by George H. Alexander Machinery Ltd in Birmingham England, circa 1938. This motor is about three times the size of a modern equivalent and it a 2-speed pole-changing motor, rated at 2 HP at 1420 and 700 RPM.

I added two externally-mounted 80mm 230VAC fans to cool the speed controller's heatsink. The exhaust holes were drilled into the back face of the box so flying swarf cannot enter the box easily. I also cut a viewing hole into the lid, covered with Perspex, to be able to see the three LEDs and the state of the controller.

**Hans Moll,**
**Bowral, NSW.**

kill off new amateur radio hobbyists. Very few people will ever get to know about Amateur Radio.

**Kim Jones,**
**Mitchell Park, SA.**

*Comment: we think the encryption of radio communications for public utilities is good. There is no doubt that the use of scanners has contributed to crime in the past. One of the SILICON CHIP staff had his house burgled as a result of thieves monitoring police communications.*


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### The demise of Notebook PCs

It is no wonder that the sales of these fantastic devices are in free fall and I believe that the blame lies with the manufacturers themselves. For the past five years or so it has been difficult to buy a medium-sized notebook PC that has a decent screen resolution. Why are we lumbered with a lousy resolution of 1366 x 768 pixels, with very little choice for a higher one? If available, then the range tops out at 1920 x 1080.

For many years, I was using Dell D600 (NT4) with a resolution of 1024 x 768 and then had a Dell D610 with a screen resolution of 1440 x 1050 which was fantastic; many more lines of text or spreadsheet cells were available to use!

Now with Windows 7 or 8 and the latest "standard" notebook hardware we've gone seriously backwards. And then today we see small new devices (Surface Pro 3 – 2160 x 1440; Google Nexus 9 – 2048 x 1536; Galaxy Tab 10.5 – 2560 x 1600 etc) knocking the socks off the screen resolutions of "standard" PCs by comparison.

I was just about to buy a Sony Vaio Pro 13 (which had excellent resolution for its size and appeared to be a very well resolved machine) when Sony pulled the plug on its PC division. It seems that there are few machines in the Sony Vaio Pro 13 class so my money may follow the Surface Pro 3 (i5/256GB) but I have to pay for the "Surface Pro Type Cover"!

**Mark Schjiff,**
**Melbourne, Vic.**

### Isolating high voltage probe for oscilloscopes

Congratulations to Jim Rowe and Nicholas Vinen for the Isolating High Voltage Probe in the January 2015 issue; a great project!

I recently acquired a Gabotronics XMEGA Xprotolab, a tiny mixed signal oscilloscope with a built-in OLED screen and a USB interface to an open-source scope application for Windows and Linux. It's a fascinating gadget, intended I think for embedded applications but lacking any kind of useful attenuator and having very flimsy input protection.

It occurred to me that an extension of your project to provide switchable gain on the output side would be an ideal complement to the isolation and switchable attenuation already provided. With two channels of this and an Xprotolab, one could have quite a useful scope at limited cost. In kit form, it could be cost competitive with and more useful than other entry-level scope products.

**Neil Higgins,**
**Grange, Qld.**

### Oscilloscope competition winners announced

Rohde & Schwarz (Australia) Pty Ltd is pleased to announce the winners of our Rohde & Schwarz HMO1002 Digital Oscilloscope Competition, which was featured on page 5 of the November 2014 issue of SILICON CHIP magazine. Congratulations to Steve Zoneoff of Cistech and Bob Dring, of Microcraft.

We would like to thank all those who participated in the competition. If you need any further information on our products please don't hesitate to contact us at sales.australia@rohde-schwarz.com

**Lyndell James,**
**Rohde & Schwarz (Aust.) Pty Ltd,**
**North Ryde, NSW 2113.**

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| Max limited term discharge rate: (with <1000mAh battery) | 150 Watts |
| Accuracy levels: | <2% Amp load<br><0.5% Volts |
| Max operating voltage: | 55 Volts (48V Lead Acid Telecom supported) |
| Max discharge rate: | 40 amps (Battery dependent, 100W continuous) |
| Min discharge voltage to maintain 30 amps: | 0.9Volts (Battery dependent) |
| Min Voltage for 40 amp discharge: | 2 volts at completion of test (Battery dependant) |
| Min discharge rate: | 0.01 Amps |
| High performance micro controller with built in USB interface and 12 bit A/D conversion. | |
| 'System Ready' and 'Test in Progress' LED indicators. | |

*CBA IV does not have charging capabilities and will discharge battery during testing. Primary cells will be unusable after testing. MI recommends the CBA IV for batch testing of primary cells. Rechargeable cells will require recharging on a suitable charger shortly after testing.

#Optional accessories including probes, extended software and amplifiers are also available. Sold separately.


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## Mailbag: continued

### Argus technology would have only a minimal benefit

With reference to Publisher's Letter in December 2014, I have always enjoyed the fact that SILICON CHIP has had the courage to initiate a debate about technology, science and their effects on society. Please keep the debates going. I enjoy them and it is good for our democracy.

Crime is not caused by the lack of technology and therefore I don't believe that the application of technology will stop it. The Publisher's Letter discussed the application of the Argus-IS WAPS system technology to crime fighting. Fascinating. There is a great deal of crime which takes place under cover and can not be seen from the sky.

There is an enormous amount of crime, including terrorist crime committed in front of security cameras. After the Boston Marathon bombing in early April 2013, the bombers were afterwards seen on video recordings, placing their bombs and were then identified.

All the CCTV and surveillance technology didn't prevent the tragedy and didn't catch the bombers; the American FBI had to ask American citizens to help them with that. There are numerous examples of the inadequacies of technology used in fighting crime and terrorism.

Governments have enacted anti-terrorist legislation which provides us with no protection whatsoever. That was demonstrated a little while ago in Sydney; very tragic. They have taken a good deal more from our democratic franchise than they have given in return. The government's response to the terrorist threat has been lugubrious, pusillanimous and cowardly, while promulgating fear and uncertainty.

Therefore I would regard the installation of the WAPS technology as detrimental, with only minimal benefit and it would be very costly.

**Robert Thomson, VK4TFN,**
**Kedron, Qld.**

### Microcontroller projects should have a boot loader

I would like to suggest that the microcontrollers of future SILICON CHIP projects contain a boot loader whenever possible. The reasons for my suggestion are simple. All my life, I have only been able to program in BASIC and assembler. I have never been able to comprehend the cryptic syntax of languages like C with any ease which meant that I could not program microcontrollers.

Then along came PICBASIC and PICBASIC Pro and I have never looked back, having now written hundreds of programs. But I have always been limited to the 8-bit versions of the PIC chips and when the 16-bit and 32-bit PICs arrived, I could not use them; until now.

A comment on the Backshed Forums introduced me to Firewing. As I understand, it is a BASIC to C translator

which makes use of the free C compiler from Microchip. It generates compiled code for the 32-bit PIC chips and I have proven this with a chipKIT Uno32 PCB from DIGILENT and bought from Element14, code 189-3211.

The PIC32MX320F128H controller contains a boot loader which I have found to be relatively easy to use and trouble-free. I have never used boot loaders with my projects because I have been able to program the PIC chips directly but a boot loader can avoid a lot of hassles.

The main hassle (and complaint) has to do with Microchip and that huge program MPLAB/MPLABX. I have always had MPLAB on my computer because PicBasic Pro needs MPASMWIN but I have never used MPLAB. It has no advantages over my current system and introduces unnecessary complexity.

Firewing can generate code for the PIC chips which can be programmed directly into the controller using PICkit 3. So I bought one. PICkit 3 operates from MPLAB/MPLABX but thankfully it does not involve much use of it. Then I discovered that MPLAB wants to phone home to be able to use the PICkit 3. But my main computer is never connected to the internet, to maintain the best security. Consequently, I cannot use the PICkit 3 and I cannot program the 32-bit PICs directly.

But I can still program via the boot loader. In fact, it would seem that I could program any of the chips if they had a boot loader installed and I do not not need a huge piece of software to perform the download. Considering the ease of use that I have had using a boot loader, I believe that it would be worthwhile using a standard boot loader with any brand of microcontroller in the future.

By the way, Firewing is free and is available from www.firewing.info The language is similar to VB.NET.

**George Ramsay,**
**Holland Park, Qld.**

## Argus surveillance over cities not wanted

I would like to comment on the Publisher's Letter on the topic of the Argus surveillance system, in the December 2014 issue. I believe that such material should largely reflect the contents of the magazine and not be used as a platform for launching one's personal opinions on other subjects.

In respect of the Argus surveillance system, I would have thought those keen to propose such a scheme will need to allow cameras to be fitted into their properties so we can all see what they are doing! After all, in this "1984-like" scenario the real problem comes down to "who watches the watchers"? Until there is strong legislation to control its collection and distribution, I think we should all be concerned.

**Graeme Clinch,**
**via email.**

*Comment: consider how much easier it might have been to follow and apprehend those Parisian terrorists if a system such as Argus had been installed above the city.*

## Time domain reflectometry in years past

Further to your article on TDR, I would like relate my experiences with a Pulse Echo Tester, made in Sydney by TMC. It was similar to the photo of

## Mailbag: continued

### Petrol mowers are a source of air and noise pollution

The subject of petrol power tools in the Publisher's Letter in the January 2015 issue is long overdue for discussion and comment. How much do the millions of petrol engine lawn mowers contribute to our carbon footprint? The storing of fuel and lubricants around the home is also a safety concern for every parent with children.

My own lawns have been mowed by my cheap electric lawn mower purchased 10 years ago. I have 240VAC power points on the outside corners of my house, wired correctly to a fuse box containing a 1kW modified sinewave inverter and two 12V car batteries, fed from a 120W solar panel and charge controller.

When not mowing, the batteries hold up the outside security lights at night, provide power for the vacuum cleaner in the house when required, plus many other useful items which get their power from this installation. The benefits are real, with free renewable energy being used in a productive, responsible way.

**Harry Hoger,**
**Quakers Hill, NSW.**

"Flossie" in the December 2014 issue. It used a hybrid to send the pulse and the resulting return signal was read on a 5-inch CRO. The pulse width started at 4kHz and the controls allowed for frequency increase and for range.

While working at Alice Springs in the late 1960s we had a problem when we lost all lines north to Tennant Creek, 315 miles away. We were able to get the line foreman at Barrow Creek (180 miles), so it was north of there. I had the line foreman do a patch that disconnected Barrow Creek equipment and using the PET it gave a location of about 65 miles north of Barrow Creek (total distance 245 miles).

The line foreman said that there was a road crossing at about 62 miles. He went straight there and found that the wires had been pulled down by a truck with a high load. This location was helpful as the line was not close to the road for quite a long distance.

While later working on the Eyre Peninsula the old private party line was replaced with 20lb loaded copper cable. The heavier cable reduced the resistance and at 36km this was 1600Ω. An 88mH coil was inserted in series every 2000 yards and this made the line a low-pass filter with maximum pass frequency of just under 4kHz and an impedance of 1200Ω, to give a flat line attenuation loss of 6dB at 36 miles.

By using the PET at 4kHz bandwidth and a special hybrid balance network, fault location could go to the full distance. Speed of propagation came into play, as the cable was about 18µs per mile and the loading coil was 107µs per mile (total = 125µs/mile). Faults were able to be diagnosed to the nearest loading coil and this saved a lot of time in locating them.

**Brian Dunn,**
**Old Noarlunga, SA.**

### Multi-spark CDI should drive multiple ignition coils

Bravo Silicon Chip for the Multi-Spark CDI in the December 2014 issue. But it would have been informative if some brief mention was made as to how the September 1997 Multi-Spark CDI was obsolete. Back then, I looked at it with the view to adapting it to a multi-coil V6 Commodore.

I recall that my envisaged changes and improvements were: (1) to use an off-the-shelf toroidal transformer; (2) have the 300V supply feed a separate switching PCB for each coil; and (3) decrease the multi-spark gap from 200µs to 150µs.

The published oscilloscope graphics seemed to indicate it should be possible. The reasoning for this is that the best energy transfer for ignition supposedly happens during the corona discharge before actual arcing. I would recommend readers google "pulsed corona discharge ignition".

The above design changes would allow the device to be also used for multi-coil engines (both cars and especially motorcycles). These are now

### Errors in Stromberg Carlson radio circuit

One can only assume that the circuit of Stromberg Carlson 5A26 in the Vintage Radio page of the January 2015 issue was drawn in a mad rush, on the Friday before a major holiday. It appears in the same way in the AORSM. The 6J8 is drawn as a 6A8.

As can be seen from the data books, they are far from the same. It would have been nice to actually put all of the elements into the diagrams of the valves. The 6A8 was not really a shortwave valve and was superseded in that role by 6J8 (& Philips equivalent) with its separate, direct-coupled triode exciter.

However, these two valves will actually interchange, despite appearances. The 6J8's triode grid actually lines up with 6A8's oscillator grid. But on some sets (not all) like the Astor JJ, a 6J8 will cause compression of the band and the lower end will creep into the NDBs (non-directional beacons). I have often used the alternative valve to check a set and sort the calibration out when I don't have the correct one for that set.

**Marc Chick,**
**Wangandary, Vic.**

*Comment by Graham Parslow: the 6J8 and 6A8 are certainly not interchangeable types. In this case, Stromberg Carlson erroneously stamped 6A8 on the model 5A26 featured in January 2015 but the valve is a 6J8. They made the further error of submitting a circuit diagram to the AORSM correctly labelling V1 as a 6J8 but depicting a 6A8. The featured radio has serial number 18167.*

*Another 5A26 in my collection with serial number 12706 (presumably an earlier assembly) correctly indicates a 6J8 on the chassis. An easy conclusion would be that it was planned to swap to a 6A8 and they did not follow through but did change their official circuit diagram for submission to the AORSM.*

*Another contemporary Stromberg Carlson 2-band model 5A36 in the author's collection is stamped with 6J8 and is true to the indicated V1 on the AORSM circuit diagram.*

*However the valve drawn for the 5A36 is again a 6A8. That 2-band 5A36, with serial number 15358, shares the same case as the 5A26 and almost all of the circuitry. The "Stromberg-Carlson" as written on serial number 15358 (correctly stencilled 6J8) matches the more Gothic font seen on serial number 12706.*

a significant proportion of vehicles, so I am perplexed as to why these are not catered for in this new design.

Furthermore, I challenge the wisdom of "device cut-off at low battery voltage". It makes more sense to be able to keep going than be stranded.

Also, I note that the article recommended a possible slight reduction in spark advance. Though the faster rise time may be a factor, I believe that the primary cause for this is the greatly increased ignition energy. This increased ignition energy should also allow running on slightly leaner mixtures.

**J. Williams,**
**Carrara, Qld.**

*Comment: the 1997 CDI design was clearly obsolete, with key components no longer being available. The new CDI design is intended for older engines, as detailed in the December 2014 issue. We specifically did not cater for modern engines since the manufacturers' standard ignition systems are specifically designed for combustion in their engines and they have very "hot" sparks in any case, with spark duration up to two milliseconds.*

*It's also possible that with ignition burn detection in modern engines, a CDI system may cause an error code to be produced by the engine management system. An error code could be due to the short spark duration or detection of the following multi-sparking that may be flagged as faulty or delayed spark timing.*

*The low voltage cut-out could be changed for operation down to about 7V (the TL494's low voltage limit) if the low battery dropout detection is disabled for IC1. The L6571 is driven from the 300V supply, so as long as the 300V is sufficient that section will work OK.*

*Disabling the low-voltage cut-out simply involves removing the 10kΩ resistor connecting pin 2 of IC1 to ground. Mind you, the engine management systems in many modern cars*


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## Mailbag: continued

### Getting a fix from SILICON CHIP

I always look forward to my monthly fix of SILICON CHIP and I particularly enjoyed the January 2015 issue. I enjoy Publisher's Letter which very often illustrates that we electronic nuts can sometimes think about other things.

My beef is particularly with petrol-driven leaf blowers – noisy polluting beasts often used quite pointlessly. Often, the leaves are noisily shoved one way by the blower (no dustpan in sight), only to be immediately blown back by the next puff of wind!

The January issue also provided some consternation here. In the article about the PicoMiniCube (page 76), I am struggling with the maths in the concept that "only about one third" of errors are due to incorrect component placement while "the other 90% is poor soldering"! Also, I would not like to trust any electronic product developed or tested in "a typical workshop" as apparently shown in the photo on page 88. Here a delicate PCB is just centimetres away from a pedestal drill, which must emit swarf when in use. Mixing mechanical and electronic workshops is asking for trouble!

With regard to the never-ending debate about climate change, it appears that many well-qualified climate scientists (I do not count people qualified in other disciplines) and certainly a number of mass circulation newspaper chains are strongly for or against. They can't all be right. Surely, we have enough data for one side or another to admit that they were mistaken and so come to a consensus and provide sensible guidance for us lay persons!

**Alan Ford,**
**Salamander Bay, NSW.**

*may not let the engine start if the battery voltage falls below 9V, in any case.*

### Comments on the climate change debate

Your comments in the Mailbag section in December 2014 issue that "some climate change believers also subscribe to the Gaia hypothesis" is about as relevant as my saying "some climate sceptics believe in Creationist theories". Neither comment adds much to the climate change debate.

In fact, I wonder if an electronics magazine can in general add much of value to whether or not climate change is occurring – this is essentially a specialist area of physics expertise where one needs to understand the "devil in the details" to come to correct conclusions – just as one needs to have electronics "devil in the details" expertise to design the good valve amplifier in the same issue.

Where an electronics magazine may contribute usefully to the debate is what are the effects of technical measures currently being promoted and so your magazine was right to publish the websites showing the negative effect of measures such as wind power – though as your Publisher's Letter points out (in another context of spy satellites), one always has to balance the positives against the negatives.

The last research I saw from Oxford University (where I did my PhD in physics) suggests that a mixture of energy sources, including coal and nuclear, are needed to produce optimum results (at least in the short/medium term) but that this optimum mixture will depend on the particular country and will vary with time as technology and economics change (particularly as the cost of 'externalities' of pollution and climate change become 'internalised').

As with judgements on what technical measures to take most effectively and economically, judgements on climate change itself are best left to the real experts in their field, not armchair ones. And real experts are rarely complacent about or absolutely certain of their conclusions.

**Dr Rod Crawford,**
**Cygnet, Tas.** SC


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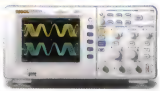

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# Look mum: no hands!

# It's the AirWheel

by Ross Tester

**What has one wheel, no handlebars, no "apparent" controls but is enormous fun to ride once you get the hang of it? An accelerometer-stabilised and microprocessor-controlled AirWheel, that's what! SILICON CHIP recently took one for a spin – literally!**

**You must have seen the Segway** – and wondered how anyone could ride such a gravity and balance-defying device. Yet people – many people – have mastered the art. So much so that you now even see TV cameramen zipping up and down the football sidelines on their Segways – no doubt saving their own energy but just as importantly, giving a smooth, jerk-free picture back to the director.

Well, if you thought the Segway (with its two wheels) was gravity and balance-defying, folks, you ain't seen nuthin' yet!

## Here comes the Airwheel!

The first thing you notice about the Airwheel is that there is only one wheel. (In truth, there are models with twin wheels but they're only a couple of centimetres apart so in our book, that qualifies as one!)

The second thing you notice about the Airwheel is that, unlike the Segway (and imitators) there is nothing to hang on to – no handlebars, no balance straps, nothing.

The third thing you notice about the Airwheel is that it looks impossible to ride – until you see someone glide by without (apparently) a care in the world. You'll see Airwheel riders with a bit of practice under their belts riding with hands in pockets, hands on hips, hands anywhere except spread right out grasping for balance! There are even plenty of videos of riders with one foot in the air . . .

The Airwheel comes in a variety of models, which are all variations on a theme. And there are other similar devices on the market such as the Solowheel and the Electric Unicycle. But we'll concentrate on the Airwheel, mainly because we got to have a play with one for a week or so, courtesy of Airwheel Australia!

## OK, what is an Airwheel?

In a nutshell, it's a battery-powered, microprocessor and gyroscopically-controlled single wheel personal transportation device. It has a pair of foot supports (they call them pedals, but they don't pedal anything!) emerging from

each side; to ride it you simply step on it and go! To move forward, you transfer some of your weight forward. To slow down, stop or even go backward, you transfer some of your weight backward. To go left . . . you've guessed it – you transfer some of your weight to the left (and similarly to go right).

The manufacturers describe it as "incorporating the latest in fuzzy software, posture control, motion control, anti-electromagnetic interference and a gyroscope."

Breaking open the nutshell, the Airwheel is battery powered and has a maximum speed (depending on model, which in turn depends on which battery is fitted) of about 12-18km/h or so. In fact, where legal (see panel overleaf), 12km/h is usually the maximum speed allowed.

It has three-way gyroscopic control to maintain balance and direction with a number (again depending on model) of accelerometers to sense the rider's weight transfers. A microprocessor takes over then to apply power to the pancake-type electric motor, which is basically the entire wheel.

A Lithium-ion or Lithium Phosphate rechargeable battery of between 130 and 340Wh (depending on model) will give around 15-21km or so range, although this depends on both the weight being carried (maximum 120kg) and the inclines you try to traverse. We've seen figures quoting 15-30° maximum on the largest models but we find even the lower figure a bit hard to believe: the ramp up to the first-floor SILICON CHIP offices is about 10° and we couldn't get the Airwheel up that! Battery life is rated at up to 1600 charge/discharge cycles.

The motors are rated at up to 800W and drive wheels up to 36cm in diameter

## Where do they come from?

The Airwheel is designed and manufactured in Changzhou, China but some references say it was invented in

**Resplendent in floppy hat and sunnies (safety equipment, no doubt) our intrepid Editor got the hang of the Airwheel within minutes (albeit with trainer wheels fitted), zooming around the carpark. This is the two-wheeled model – it's slightly easier to learn to ride than the one-wheel model shown at left in carried "transportation" mode.**

**Inside the AirWheel motor: you can see the 56 coils around the edge of the rotor (which remains stationary!), with 56 very powerful magnets alongside around the stator. The tyre goes on the outside of the stator, shown assembled above.**

England. There is now world-wide distribution for the Airwheel and any number of organisations are advertising it, even on ebay.

## Weight and portability

There are quite a few Airwheel models available (see opposite) but all have one thing in common – their portability. They're touted as being ideal for riding to the station and carrying onto a train. At 10-15kg, we say "good luck" – that's quite a weight to tote up and down station stairs etc – or even carry for any significant distance. Possible, yes. Practical? Ummm . . .

## The motor

Like most small electric-motor-powered people movers, the Airwheel uses a brushless DC motor (BLDC), also known as a pancake motor.

Unlike most electric motors, where (as you would expect) the rotor spins and the stator remains stationary, in this pancake motor the rotor remains rigidly fixed to the frame and the stator spins. In the Airwheel, the stator actually forms the wheel halves, so it provides the power to move.

The motor has 56 very powerful magnets firmly positioned around the outside of the stator and 56 matching coils attached to the rotor. The microprocessor switches power to the appropriate coils at the appropriate time, resulting in a magnetic field which either attracts or repels the magnets. So the stator moves either toward or away from the coils . But by the time the stator reaches the point where equilibrium would be reached, power has been switched to the next coil, and then the next, and the next – resulting in the motor turning forward or reverse, always attempting to maintain that magnetic balance but never achieving it while ever power is applied.

Rather than running on DC straight from the 60V battery, the Airwheel is driven by a three-phase inverter through its microprocessor-powered controller – what this means is much more power available from the motor for the amount of voltage applied. Just as importantly, it enables very good speed control over the motor, an important consideration when your only means of control is small shifts in body weight!

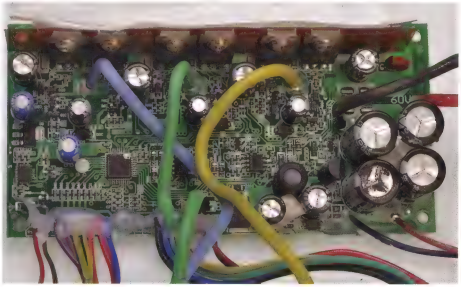
**OK, so he's showing off . . . but this rider ably demonstrates the stability of the airwheel, thanks to its gyroscopes, accelerometers and microprocessor.**

## Safety features

Learning to ride the Airwheel is at best a little daunting because it goes against everything your brain tells you about balance and stability.

For this reason, detachable "trainer wheels" are supplied which fit as outriggers and help the new rider board the Airwheel and commence to ride. Even so, the first hour or so is likely to be an on/off, stop/start affair.

Gradually, though, you'll learn that the Airwheel is actually assisting you



**The AirWheel controller board. The three pairs of MOSFETs at the rear provide the 3-phase drive for the motor – the rest of the circuitry keeps the wheel stable.**

by countering the natural tendency to tip over.

We've already mentioned the microprocessor and gyroscopic control. There's an automatic speed controller built in to some models, whereby the front of the foot platform rises above 12km/h to prevent further acceleration. This also actuates when the battery level falls to 10% of capacity – in this case the Airway decelerates to a complete stop.

A sensor will stall the motor when the Airway inclines more than 45°.

| airwheel | | | | | | | |
|---|---|---|---|---|---|---|---|
| MODEL | X3 | X5 | X6 | X8 | Q1 | Q3 | Q5 |
| MOTOR | 400W | 500W | 600W | 800W | 800W | 800W | 800W |
| BATTERY | 132Wh | 132Wh | 132Wh | 170Wh | 132Wh | 170Wh | 340Wh |
| SPEED | 19km/h | 19km/h | 19km/h | 19km/h | 19km/h | 19km/h | 19km/h |
| DISTANCE | 9-12km | 11-15km | 12-16km | 16-23km | 11-15km | 16-26km | 38-45km |
| UNIT WEIGHT | 9.8kg | 9.8kg | 11.5kg | 11.5kg | 13kg | 13kg | 13kg |
| CHARGE TIME | 1h | 1.5h | 1.5h | 1.5h | 1.5h | 1.5h | 2h |
| MAX WEIGHT | 120kg | 120kg | 120kg | 120kg | 120kg | 120kg | 120kg |
| TYRE SIZE * twin wheel | 355mm | 355mm | 405mm | 405mm | 355mm* | 355mm* | 355mm* |

## Battery and charging

The battery is inbuilt and is charged by a switch-mode charger which plugs into the standard 230VAC power point. It takes about 90 minutes to charge completely; 80% charge is achieved in 60 minutes.

We found that with intermittent use, the battery life is very good – we didn't need to recharge for the whole week we were ~~playing~~ researching.

## In use

With the training wheels fitted (they can be removed quickly) we found riding the AirWheel relatively easy. In fact, our Editor suggested that once you got the hang of it, the trainer wheels should come off to make turning easier. But none of us were game to take up his suggestion!

The lack of any handle or leash is a bit unnerving to start off with, after all, every instinct tells you that the damn thing should topple over as soon as you place one foot on it! And standing there with two feet on it and it moving away underneath you, well, that's just crazy stuff, isn't it?

But after a few minutes of leaning on someone else's shoulders for support, you find you don't need them!

## Where from, how much

Our Airwheel came from Airwheel Australia, of Frenchs Forest NSW. As mentioned earlier, there are numerous models available, ranging in price from about $750 to $1100.

The one we trialled was one of the Airwheel Q3 models, which has a recommended retail price of $1099 including GST.

Contact Airwheel Australia via their website: www.air-wheel.com.au SC

## Where *can* they be used?

That question opens a real can of worms because the way the laws are written in at least the major Australian states, they cannot *legally* be used virtually anywhere, except on private property.

In fact, they're specifically excluded under NSW (and we believe most other states) legislation. They come under the "prohibited vehicles" section of the Act, which says "These types of devices **must not be used on roads or in any public areas such as footpaths, car parks and parks**."

Motorised human transporters (MHTs) such as the WheelMan or Segway are specifically mentioned. Ref www.rms.nsw.gov.au/roads/registration/unregistered.html The legislators haven't quite caught up with the AirWheel yet!

Silicon Chip believes this is very short-sighted legislation and to some degree, appears to be the result of lobbyists trying to ensure a particular product was legal and nothing else!

Or perhaps it is simply that technology has once again significantly overtaken the lawmakers.

Of course, there are already many users who do ride MHTs in public places, either ignorant of the law, don't care, or assume they can outrun any pursuer on foot (perhaps they can!).

Indeed, in other parts of the world, Governments have been much more proactive in recognising the potential of these devices in assisting in the movement of people, whether that's to and from public transport hubs or indeed the whole journey. They recognise the potential of personal people movers and their ability to reduce the number of other vehicles on the road.

Back in Australia, the Queensland government showed significantly more foresight than NSW and Victoria by legalising human transporters, at least on public paths, on August 1 2013, providing users wear a helmet. Incidentally, section 244L of the Queensland

traffic laws demands they be fitted with a bell. Ummm – where!

Motorised human transporters are rapidly gaining favour on university campuses with both students and staff having to get from point A to point B as efficiently and effectively as possible. They're being used by staff moving around large warehouses and distribution centres and by supervisors traversing large assembly lines quickly and easily.

AirWheel have even been in discussions with large housing estate developers who would like to keep motor vehicles outside the housing areas – eg, park on the outskirts and AirWheel to your house on the pathways provided! Far fetched? At the moment maybe, but wait a year or two . . .

*Amateur* unmanned vehicles pushing the limits o

# REACH FOR THE SKY

## ... and way, way beyond

**Miniature radio and video transmitters, flight control computers, miniature high-definition video cameras, miniature GPS receivers, solid state gyroscopes and accelerometers, miniature computers and high energy density lithium polymer batteries plus advances in materials science are enabling amateur enthusiasts to make unprecedented achievements with unmanned air vehicles such as balloons, multi-rotor aircraft, fixed wing aircraft, kites and rockets. With these technologies they can fly high, fast and for great distances.**

**Achieving feats of altitude speed and long range is fine** but it is also nice for others to know about these both so they can learn and improve their own projects and to satisfy people's curiosity about such things. Fortunately there are distribution channels such as YouTube and the Internet more generally that can be used to publicise such achievements.

In this article we look at the achievements of a number of amateurs in high altitude, long range and high speed flight with unmanned radio-controlled (R-C) vehicles, along with an amateur-built manned rocket intended for sub-orbital flight, the subject of our lead illustration above.

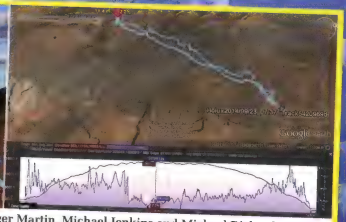
### Kites

Starting with one of the earliest flying technologies we have kites. The world record for altitude for a single kite is held by Australians Robert Moore, Michael Richards, Michael Jenkins and Roger Martin. On September 23, 2014 they set a world record of 16,038 feet above the launch point (current practice is still to measure aircraft altitude in feet).

# ltitude, long range and high speed

**Part 1:**
**By**
**Dr DAVID MADDISON**

Artist's conception of spacecraft featuring Copenhagen Suborbital's HEAT1600 rocket engine. At the top of the spacecraft is the astronaut capsule or MicroSpaceCraft (MSC) and atop that is the Launch Escape System. The escape system is a rocket that will carry the MSC to safety in the event that the main propulsion rocket malfunctions.



No, it's not a tent they're standing in front of: Bob Moore, Roger Martin, Michael Jenkins and Michael Richards with the huge kite used to set the world record of 16,083 feet in September last year. At right is the ground track and altitude and speed readings from the Horux GPS data logger. 12,620m of high strength Dyneema line were spooled out for this record breaking flight.

The record was achieved at the Cable Downs sheep station near Cobar in NSW. Australia's Civil Aviation Safety Authority (CASA) gave them special permission for the flight and for previous attempts and granted them an aircraft-free zone, with permission to fly to 17,370 feet.

It took extensive and often delicate negotiations to achieve approval and some unusual conditions applied but it was finally granted although, disappointingly, CASA charged the team a hefty $560 fee (introduced around 2007) for every flight period, which certainly does nothing to encourage other people trying to achieve something. To their credit, the team persevered with their negotiations and to CASA's credit, they eventually did grant permission. Hopefully it will be easier to obtain permission for their future efforts and other pioneers who want to push the envelope.

An important part of this challenge was being able to validate the altitude achieved. A combination of GPS data loggers and GPS telemetry were used from the kite with both manual recording and PC recording at the ground station.

The line used was over 12km of ultra-high-strength

Dyneema (the world's strongest commercial fibre on a weight for weight basis) which was fed from a mechanical winch.

The GPS equipment on the kite was kept in an insulated box as the temperature at altitude could be as low as -20°C. The accuracy of the GPS data was verified against a fixed survey datum by a registered surveyor. For telemetry GPS/Flight using a u-blox receiver was used and for GPS data logging a Holux M-1200e. The Holux unit weighs just 32 grams.

There is an extensive amount of detail on the kite and its technology at Robert Moore's website, www.kitesite.com.au/kiterecord

## Weather balloons

Balloons are another early flight technology - but they too have gone high-tech.

There are two main types of balloon used by amateurs. The first is a traditional weather balloon, often made of latex. These can be filled with either helium or hydrogen, although hydrogen carries significant safety risks if not handled correctly (although, unlike helium it is a renewable resource and helium prices have – no pun intended – skyrocketed recently with a world-wide shortage). Weather balloons can fly as high as 30km (100,000ft) and more.

On February 1st, 2014 an enthusiastic group of Queensland Radio Amateurs (VK4HIA, VK4NBL, VK4AHR, VK4BOO, VK4FSCC and VK4FADI) launched a high altitude balloon (HAB) near Dalby. It achieved an altitude of 107,837 feet and was equipped with a camera and transmitting equipment for APRS (Automatic Packet Reporting System), RTTY (radioteletype) and had a basic FM transmitter. They documented their achievement with a video posted at "High Altitude Balloon Launch and Recovery - Dalby, Queensland VK4HIA – Balloonatics" http://youtu.be/5cRgBPqpJmA

The current record for an amateur high-altitude unmanned balloon is 145,590 feet achieved on 11th August 2012 by the Bello Mondo team. Many amateur balloon records and other information is available at www.arhab.org/

Some people launch balloons and use a Raspberry Pi as the flight computer. A Frenchman, Fabrice Faure, has taken some amazing photographs and his work is detailed on his Fab4Space! web site at http://fab4space.com/?lang=en

**Frame capture of YouTube video of the "Balloonatics" (Queensland Radio Amateurs) immediately after the balloon burst at 107,837 feet (near 32km). When latex balloons burst they ideally shred into many small pieces that fall clear of the balloon and don't interfere with the parachute or payload (this does not always happen, however). A piece of balloon debris can be seen in the lower right corner and the lines are attached to the payload and parachute.**

## PICO balloons

The second type of balloon in use is, perhaps surprisingly, the humble mylar "party balloon". These are the small silver-coloured balloons that might have "Happy Birthday" or some other greeting written on them.

These balloons have been used to carry as payload tiny electronic packages, comprising a GPS receiver, a radio transmitter, a battery and some even carry tiny solar panels. The entire electronic payload and support string may weigh less than 13g.

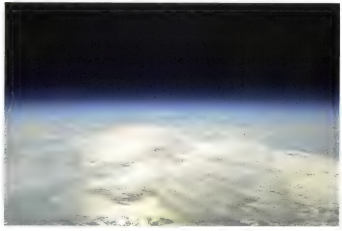
They are known as PICO balloons and require no license or permission to launch and can drift at an altitude of around 8,000 metres and can reach very great distances from their release points.

Note that we are talking about actual party balloons bought from a party supply shop, not special balloons of a similar design.

Melbourne amateur radio operator Andy Nguyen, VK3YT, has released many PICO balloons and details their trips at http://picospace.net/ From Melbourne, PICO balloons have flown as far as Adelaide, New Zealand, Fiji and South America. Most of the long range flights are solar powered (ie, they contain tiny solar panels), but many Melbourne to New Zealand trips are powered by a primary lithium battery.

The trackers (the electronic payload containing the GPS, transmitter, power and control circuitry) are custom designed and built for minimal weight and power budget. The total weight of the tracker is less than 13g and the transmitter power is from 10-25mW.

Andy's early model trackers transmitted on VHF and UHF and required line-of-sight tracking via the amateur radio APRS (Automatic Packet Reporting System) network or an amateur radio digital mode such as Olivia or THOR. The range achievable with the balloon at a typical altitude of 8,000m was 380km.



**The Rhone river flowing into the Mediterranean Sea from the south of France as photographed by Fabrice Faure. The picture was taken with a camera connected to a Raspberry Pi computer from an altitude of 86,000 feet.**

## Predicting balloon trajectories

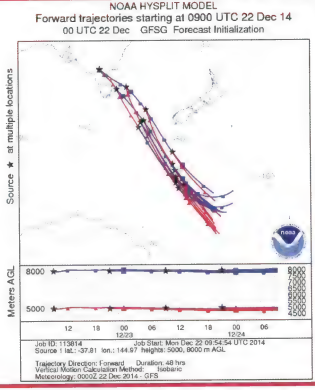
Balloon flights require a lot of planning. It is not simply a matter of releasing a balloon and hoping for the best. One has to make sure the balloon will travel in the desired direction and also have knowledge of the likely recovery area and to ensure it does not go near airports or flight paths.

Smaller balloons require no flight approval but it is still important to do the safe and responsible thing.

Fortunately there are accurate online tools to predict balloon paths which should be used before launching any missions. One tool is "Balloon Trajectory Forecasts" at http://weather.uwyo.edu/polar/balloon_traj.html It can output a GoogleEarth KML file which will show the predicted balloon path on a GoogleEarth map. It will even predict the balloon burst and landing position.

Another balloon modelling program is HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) available free at http://ready.arl.noaa.gov/HYSPLIT.php it can predict many types of atmospheric transport and dispersion paths such as smoke and volcanic ash plumes but there is also a section for balloons.

As an example of what this model can do, the coordinates for Melbourne were entered and a map was generated showing the predicted path of a balloon released from Melbourne at the time specified. Multiple trajectories can be displayed corresponding to different altitudes and times of each new "starting point" correspond to where a split in the trajectory is shown.




Olivia and Thor are multi-frequency shift keying (MFSK) transmission modes for digital data over radio waves.

Andy is currently testing HF for a longer tracking range of many thousands of kilometres using weak signal propagation protocols such as JT9, JT65 and WSPR. So far the maximum range a tracker signal has been received using WSPR from a PICO balloon is 16,000km – with only 25mW of transmitter power!

**A typical PICO balloon launch showing balloon, payload and two tiny horizontal solar panels.**

WSPR is an open source software program that uses a protocol for probing radio propagation paths from very low power transmitters. Each transmission contains a transmitter's location, call sign and power. Users who receive transmissions upload reception reports to the WSPRnet database http://wsprnet.org/drupal/. The program is capable

**WSJT-X software (slightly modified) for monitoring the extremely weak transmissions from PICO balloons. Windows for WSPR software are also visible. WSJT is also an open source program to facilitate low power transmissions between radio amateurs. WSJT-X is an experimental version of this program. JT9 and JT65 are transmission modes supported by this software designed for extremely weak transmission which when received are many decibels below the noise floor.**

**A PICO payload weight around 12g. Note the u-blox GPS receiver. This tracker transmitted at 434.650MHz USB with 10mW power. It had a dipole antenna and the transmit mode was 100 baud RTTY, 425Hz shift, ASCII 8, None, 1.**

of decoding signals that are not even audible to the ear and are -28dB in a 2,500Hz bandwidth.

According to Andy, the main purpose of this work is to study radio weak signal propagation, and at the same time have fun working with a community of volunteer tracking stations around Australia. None of these would be possible without the network of volunteer tracking stations assisting with the launches. Their contribution to the success of the PICO balloon flights is greatly appreciated.

Until recently, the longest PICO flight has been from Melbourne to Brazil which took place from the 12th July until the 21st July 2014, a distance of 16,000km, just a few days after the World Cup (see right)!

Unfortunately PICO balloons don't remain aloft forever. The weight of rain can bring them down, as can UV degradation of the mylar material causing them to leak helium.

**Ground track of Andy Nguyen's PS-30 flight. It was launched in Melbourne on 27th December, 2014 and at the time of writing (12th January, 2015) it is still in flight and was just off the coast of Africa. If it remains aloft long enough, wind predictions indicate there is even a possibility it could return to Australia! It has tiny solar panels and a 25mW transmitter on board. At night the electronics go dormant because the low temperature, as low as -65°C, prevents the battery from working. You can track the progress of the current flights on Andy's web site at http://picospace.net/tracker/new Alternatively you can track this and other high altitude balloons at http://tracker.habhub.org/**

## The law and unmanned aircraft

*Silicon Chip cannot give definitive legal advice about the legality of various activities described here, either for Australia or overseas as the laws are subject to change and are also subject to ambiguity in some cases. It is up to prospective operators to fully familiarise themselves with the relevant regulations.*

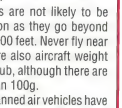
Certainly, people in Australia should familiarise themselves with the Civil Aviation Safety Authority's (CASA) regulations CASR Part 101. Advisory circulars for Part 101 can be seen at www.casa.gov.au/scripts/nc.dll?WCMS:STANDARD::pc=PC_91039 and the regulations themselves are at www.comlaw.gov.au/Details/F2014C01256/Html/Volume_3#_Toc403541324

You may also be interested in looking at proposals for regulation changes at www.casa.gov.au/scripts/nc.dll?WCMS:PWA::pc=PARTS101

As with any activity it is important to exercise common sense and individual responsibility and to set the highest possible example for one's endeavours. There are always some politicians and bureaucrats who enjoy nothing else than removing the simple pleasures from people so if everyone is sensible, it is less likely for them to do this.

In general, unmanned aircraft should not be operated near people or building structures and only in remote areas and within the rules as they apply. There are height and range limits that apply and aircraft should not be flown beyond visual range for non-commercial flights (there are exemptions for commercial operators after extensive training and licensing).

There are also special rules for balloons which can be flown beyond visual range under certain circumstances. "Small balloons" that can carry a payload of no more than 50g such as the PICO balloons described here are unrestricted and require no permission to fly but are still subject to "common sense" considerations.



Long range non-commercial FPV flights are not likely to be legal in Australia without special permission as they go beyond visual range and exceed the height limit of 400 feet. Never fly near airports or in controlled airspace. There are also aircraft weight limits which apply of 25kg or 150kg if in a club, although there are no restrictions on aircraft weighing less than 100g.

People have rightly been fined when unmanned air vehicles have flown too close to people and crashed and injured them (see, for example, www.abc.net.au/news/2014-11-13/drone-operator-at-geraldton-marathon-fined/5887196).

Note also that in Australia there are limits to the permitted radio power and frequencies used for uplinks and downlinks to and from RC aircraft.

For the future of this hobby it is important that operators do not give the authorities any excuse to regulate it out of existence as is the case of with many other fun activities.

This is partly because this technology is rapidly changing and laws don't necessarily keep up with the state of play and often because politicians and bureaucrats and some elements of the media usually do not understand the technology or the fun aspect of anything.

**The radio controlled (RC) aircraft that was flown to the edge of space on a weather balloon, prior to launch. It is a Multiplex Funjet, a very fast RC model in its own right but in this application it was used as a glider and no motor was installed.**

Apart from that, helium is notoriously difficult to contain and would eventually leak out.

If you want to participate in tracking these PICO balloons you can go to Andy's website and sign up for the mailing list which will advise you of launch times and path predictions. You will need an inexpensive software defined radio (SDR) (see SILICON CHIP May & October 2013), an appropriate antenna and some free modified WSJTX software from the PICOSPACE website.

The balloons can be tracked at **http://spacenear.us** or if it is an APRS payload, at **http://aprs.fi**

Combining the above two aircraft types, there are also balloon-kite hybrids.

For those interested in aerial photography from kites and balloons there is a discussion at **www.paulillsley.com/airphoto/systems/balloons-kites.html**, among many other sites.

## Using a balloon as a launch platform

Combining a balloon for the launch vehicle and a radio controlled aircraft, a Swedish man, David Windestål flew a balloon to a height of approximately 108,000 feet with a payload of a radio controlled aircraft which beamed a live video feed back to the pilot.

Many problems had to be solved such as removing grease from the servos of the plane as it would freeze at the cold temperatures at high altitude and also the electronics and batteries had to be kept warm as lithium batteries are very sensitive to low temperatures; their voltage drops.

Another problem is that most civilian GPS units are designed **not** to work at altitudes above 18,000m and speeds above 1,852km/h so that terrorists or rogue states cannot use them to control missiles, so the altitude had to be determined barometrically. The distance between the launch site and the landing site was 101km.

The web site with details of the project is at **http://rc-explorer.se/projects/2013/03/fpv-to-space-and-back/** See YouTube video "Space Glider – FPV to Space and Back!" **http://youtu.be/rpBnurznFio**

Along the same lines as above there is an Australian project known as "Project Thunderstruck" (**http://project-thunderstruck.org/**).

**Artist's rendering of Project Thunderstruck re-entry vehicle. It will initially be launched from an altitude of 40km but it is planned to be developed as a sub-orbital and then an orbital re-entry vehicle.**

The objective is to carry an aircraft to an altitude of 40km and then achieve supersonic flight as the aircraft dives back towards earth. The aircraft will also be capable of carrying a payload for various experiments.

The supersonic glider will be 2.5m long and is expected to achieve a speed of Mach 1.5 and 1800km/h. This is the initial stage in development of a re-entry vehicle for which it is planned to be able to deliver a payload to space on a sounding rocket in a non-orbital flight within 2-3 years and orbital flight in 6 years.

One remarkable part of this project is that the glider

## Hydrogen and helium for balloons

Those interested in hoisting some payloads aloft have a choice of either hydrogen or helium. Hydrogen is relatively cheap and renewable but it can be hazardous in untrained hands and is not generally recommended in the ballooning community.

On the other hand, Helium is the lifting gas of choice but unfortunately it is a non-renewable resource and once released it drifts off into space. Recent reports have suggested that helium supplies worldwide are in short supply and therefore becoming more expensive.

Tanks of helium gas can be hired although it is possible to purchase a small amount of helium in a disposable cylinder. Balloon Time have a 422 litre disposable tank which is enough to fill around 50 standard latex balloons to a diameter of 230mm. I have seen such a cylinder in a party supply store in Melbourne selling for $55. Such a cylinder should be able to be used to fill mylar PICO balloons which can also be purchased unfilled at party stores. Those balloons can also be filled with helium at some party stores.

**Commander Major Jon Fletcher with the paper aircraft that set the record for highest altitude release. It carried GPS, transmitter, a camera and support electronics.**

will be designed by 12 year old student, Jason Brand, from Sydney.

## Paper aeroplane launched from balloon

People have even launched paper planes from balloons! On 13th September 2014 Fox Valley Composite Squadron of the Illinois Wing, Civil Air Patrol, an unpaid volunteer organisation, launched a paper plane from a balloon at an altitude of 96,537ft.

Tracking data was acquired via an onboard GPS and transmitted via the amateur radio APRS network. There was also an onboard video camera, temperature sensors, pressure sensors, flight computer and solar panel. The plane was 760mm long and 370mm across and weighed 424g. The launch took place at Kankakee, Illinois and the aircraft landed at Rochester, Indiana around 132km away (straight line distance).

## High speed gliders

Dynamic soaring is a process by which radio-controlled gliders (or other aircraft) can gain airspeed under particular wind conditions comprising two masses of air moving with different velocity.

Such circumstances might occur at the top of a hill. When there is a wind blowing there will be a relatively slow movement of air near ground level on the downwind side of the hill and relatively fast moving air higher up. The air vehicle is flown in loops that repeatedly transition from the fast moving air body to the slower moving air body and back to the faster air body and so on. Little air speed is lost in a properly executed loop so energy is gained every time the aircraft transitions from the slow moving body of air to the faster moving air body.

Using this technique, the current word record for an unpowered RC aircraft is 813km/h (set 22nd November, 2014). The aerodynamic stresses in tight loops at such high speeds are extreme and 100G forces can be experienced.

**The world's fastest R/C jet. It uses a micro gas turbine engine and holds the Guiness world record.**

Crashes are not uncommon and at those speeds an impact with the ground leaves few recognisable components. Structural failure mid-air can also occur. Dynamic soaring is also the technique by which albatrosses fly vast distances with little wing movement.

See video "DYNAMIC SOARING NEW WORLD RECORD: Bruce Tebo flies 505mph at Weldon with his Kinetic 130" at http://youtu.be/r7gL9uA-McY

## Turbine RC aeroplane record

It is possible to purchase (or make, if you are keen) micro gas turbine jet engines. The speed record for an RC aeroplane was set on 14th September, 2013 at 708km/h which is actually slower than that set for the unpowered glider mentioned above. The turbine engine itself weighs 1.58kg, has 18kg of thrust at 120,000RPM and burns either diesel or Jet A1. See "very very very fast Turbine powered RC Jet 440MPH Speed Guinness World Record 2013" http://youtu.be/sa-TSNeTK-A

As an aside, people have fitted these microturbines to bicycles, search YouTube for some amazing videos www.youtube.com/results?search_query=jet+powered+bicycle

## Long-range FPV fixed wing flight

With the use of flight control computers that are integrated with GPS, accelerometers, compass and gyroscopes and FPV (first person view, a video downlink giving the pilot the view from the aircraft) it is possible to undertake very long flights.

One person has achieved a very long-range FPV of 80km round trip using an electrically powered flying wing with 32 1.8W supplementary solar cells in addition to an onboard battery.

Extensive telemetry from the aircraft is shown, including GPS coordinates. It is not stated where the flight took place but it can be seen from the coordinates that it was in the Dominican Republic.

## A note on some high altitude pictures

Many high altitude pictures, including those reproduced in this feature, show pronounced apparent curvature of the earth giving the impression of a view of the earth from low earth orbit, which is about five times higher than a weather balloon.

At the altitude of weather balloons there is in fact some visible curvature of the earth but the very pronounced curvature in some pictures is more due to the effect of the fish-eye lens used on many cameras, especially the GoPro, which is a popular choice. There are numerous software applications to remove this fish-eye effect if it is not wanted but don't be deceived that you are seeing a view as if it was from orbit.

All 3hrs 25m of it can be seen online – "FPV Long Range 80km full flight." http://youtu.be/z_PxhU9i9Ng but an edited version (3.5minutes) is at "FPV, 80km and back. 2.4Ghz RC.": http://youtu.be/TfDfkjGNWSQ

### Long-range multicopter flight

Multicopters (or as they are popularly known, drones) were discussed in a feature in SILICON CHIP August 2012. They are very popular in the R-C community and new capabilities and records are being added all the time. Many multicopters are now equipped with FPV and GPS navigation. A long range multicopter flight of 20km radius (40km total flight) and is shown in a video at "Long range quadcopter fpv 20km/40km 2013/12/28" http://youtu.be/zvEHxpoDJVA

The flight time of 63 minutes is unusually long for a quadcopter – a typical flight time might be closer to 10 minutes – suggesting that this quadcopter has been highly optimised for long range flight and well beyond visual range.

The winning formula for long range quadcopter flight seems to be a light weight frame, the largest possible propellers on high torque motors and a high capacity, low-cell count battery.

In the video it is instructive to look at the telemetry data which displays mAh consumed, battery voltage, current draw, ground speed, elapsed time and heading to get an idea of what is going on during the flight.

### Flight control computers

Many radio-controlled aircraft use flight controllers to help fly and navigate them. These range from basic ones costing perhaps $30 to full auto-pilots costing up to several hundred dollars.

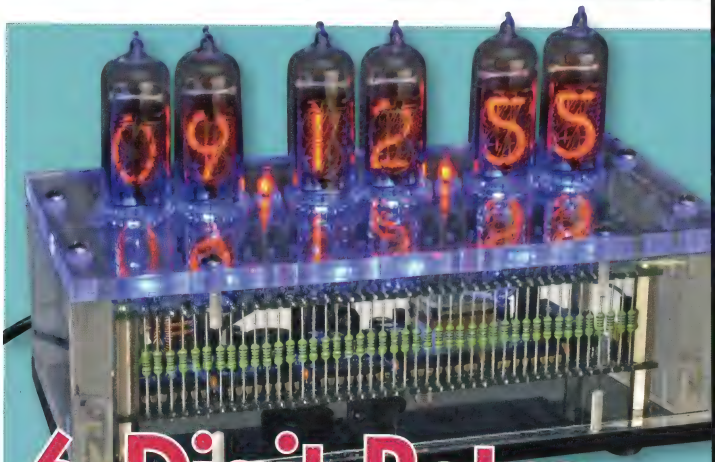
One of many examples of a flight controller that is capable of autonomous flight is the open source APM flight controller. With the addition of a GPS and compass module it can be sent on missions flying via various GPS way points.

It could be used to deliver a small package to a recipient via a quadcopter, for example (but check legality before attempting to do so!).

### Coming next month!

We've covered kites, balloons, fixed-wing and rotor-driven aircraft . . . and we've only just scratched the surface of this exciting field.

Next month, in part 2 of this feature we'll have a look at some of the amazing advances (and even more amazing plans) of amateur rocketeers. They even have a project to put a man in space! SC



# 6-Digit Retro Nixie Clock Mk

## . . . now with optional GPS time

**Revel in the retro glow of this cool Nixie Clock. But while it looks like something out of the 1960s, this is a modern design utilising a 32-bit microprocessor and (optionally) a GPS receiver module to always give you accurate time and date, automatically determined by your location. We've also added a date display function, a 7-day alarm and other new features.**

Pt.1: By Nicholas Vinen

## Features & Specifications

- 6-digit Nixie clock with date display and 7-day alarm and snooze functions.
- Blue LEDs to provide effect lighting; can be switched on or off.
- Locked to GPS time to within a fraction of a second (if GPS module is fitted).
- Automatically determines time zone and daylight saving zone within Australia, New Zealand, UK, USA, Canada & Western Europe.
- Time zone override for other locations or in case daylight saving rules change.
- Without GPS, timekeeping crystal can be trimmed to keep accurate time within less than one second per month.
- Auto-dimming of Nixie tubes and blue LEDs.
- Proximity sensor for easy date display.
- Keeps time for several hours during mains power failure.
- Easy to set time and date via two button interface.
- 12/24 hour time and leading-zero blanking options.
- All through-hole components to simplify construction.
- Complete kit available, including clear acrylic case.

**This photo doesn't do the clock justice. The glowing colours from the Nixie displays and the blue LEDs are actually quite a lot brighter and more dynamic than this photograph shows.**

.2

WE HAD SO many people at the 2014 Electronex show ask us about the Nixie Clock that we had on display that we decided it was time for a new and improved version. The original project was presented in the July and August 2007 issues of SILICON CHIP and hundreds of kits have since been sold. This new design has the same retro look but with new features.

Essentially, a Nixie tube is a neon-filled tube with 10 differently-shaped cathodes. A high voltage is applied between the anode and one of the cathodes, causing the gas around that cathode to become excited and glow. Nixies were used heavily before vacuum fluorescent displays, LCDs and LED 7-segment displays replaced them.

The biggest drawback of Nixie tubes, apart from the high voltage required to drive them (150V+), is their complex construction and thus cost. This type of Nixie tube is no longer manufactured and what stock is left will only get more expensive over time so if you want to build one of these clocks, now is the time!

So what will it do, besides display the current time (hours, minutes and seconds) on the six Nixie tubes which protrude from the top of the clear acrylic case? Well, it also keeps track of the date and will display it if you wave your hand in front of the unit. It also has a 7-day alarm with a piezo buzzer and options for 12/24-hour time display and leading zero blanking.

In addition, it can be GPS-locked so that you never have to set or adjust it. It even automatically adjusts for daylight saving time.

As with the original Nixie Clock, the blue LEDs under the Nixie tubes can be switched on and off to add extra visual appeal.

So basically this new Nixie Clock is just like the old one, only better!

## Circuit description

Fig.1 shows the control portion of the circuit, which is built onto the lower PCB. The Nixie tubes and LEDs are on the upper PCB and this part of the circuit is shown in Fig.2.

## PIC micro

At the heart the control circuit of Fig.1 is microcontroller IC1, a PIC-32MX170F256B. This is a 32-bit, 40MHz chip with 64KB RAM and 256KB flash memory in a 28-pin DIP package. Such is the march of progress that this powerful microcontroller costs less than an 8-bit chip (with just a measly few kilobytes of flash and RAM) did just a few years ago.

This large amount of flash memory allows us to do some fancy things regarding time zones, which we'll get to later. For now, let's just look at how it keeps time, drives the Nixie tubes and communicates with the GPS module, if it's fitted.

IC1 runs from a 3.3V supply and has a 32.768kHz watch crystal connected between pins 11 & 12 (SOSCI/SOSCO) with 22pF load capacitors on each pin. An internal low-power amplifier drives this crystal to form the "secondary oscillator" and this is connected internally to a Real Time Clock and Calendar module (RTCC), which keeps time even when the micro is in sleep mode.

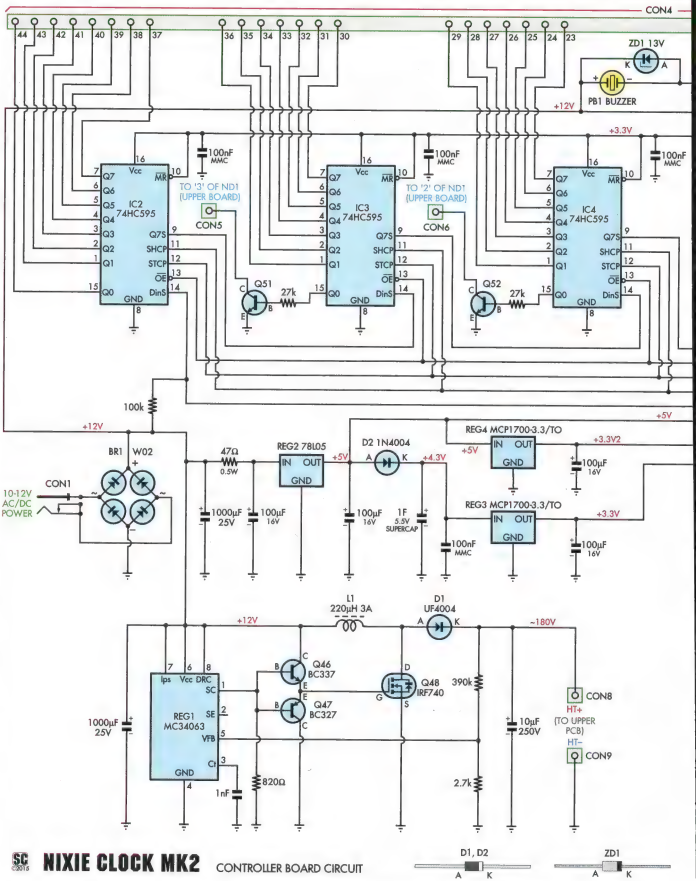
An internal clock trim register adds or subtracts a configurable number of pulses every 10 seconds to allow for inaccuracies in the crystal frequency to be adjusted out.

## Nixie segments

There are a total of 46 Nixie segments that we need to drive for the time or date display. For ND2, ND4 & ND6 (Fig.2) we drive all 10, as these are the units digits for hours, minutes and seconds. When displaying the date, these are used instead to show the day, month and year respectively.

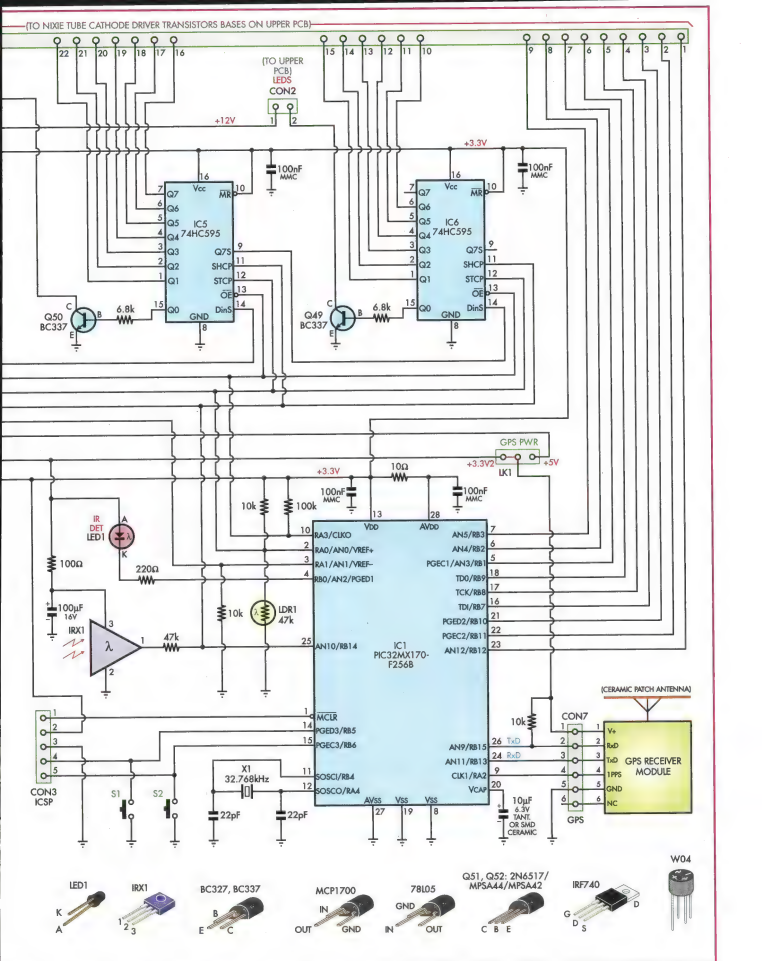
For ND3 and ND5, the 10s digits for minutes and seconds (or month and year when displaying date), we only drive segments 0-5. Similarly, with ND1, we only drive segments 0-2 for the hours (time display) 10s digit or 0-3 for the day (date display) 10s digit.

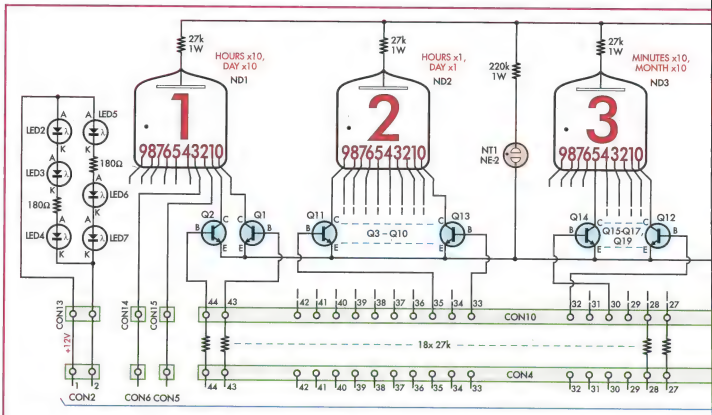
44 of the 46 Nixie segment connections are made via CON4/CON10 which are rows of pads along the front edge of the two PCBs that are connected via 27kΩ resistors soldered between the boards. The other two connections are made using wires connected to PCB pins CON5 & CON6.




**NIXIE CLOCK MK2** CONTROLLER BOARD CIRCUIT

**Fig.1: the circuit for the lower (control) board of the Nixie Clock Mk2. Microcontroller IC1 keeps time using crystal X1 and, if fitted, the GPS receiver via CON7. This micro drives the Nixie tubes via CON4 using nine of its own output pins plus 37 from serial-to-parallel latches IC2-IC6. REG1 generates the 180V HT rail for the Nixies while REG2-REG4 supply power to the micro and associated circuitry. LED1 and IRX1 are used as a proximity sensor to trigger date display.**


(TO NIXIE TUBE CATHODE DRIVER TRANSISTORS BASES ON UPPER PCB)
(TO UPPER PCB) LEDS
CON2
+12V
+3.3V
100nF MMC
IC5 74HC595
IC6 74HC595
Q50 BC337
Q49 BC337
6.8k
GPS PWR
+3.3V2
+5V
LK1
10Ω
10k
100k
IR DET LED1
100Ω
220Ω
100µF 16V
IRX1
47k
LDR1 47k
IC1 PIC32MX170-F256B
(CERAMIC PATCH ANTENNA)
CON7
GPS RECEIVER MODULE
GPS
CON3 ICSP
S1
S2
X1 32.768kHz
22pF
10µF 6.3V TANT OR SMD CERAMIC
LED1
IRX1
BC327, BC337
MCP1700
78L05
Q51, Q52: 2N6517/ MPSA44/MPSA42
IRF740
W04




**NIXIE CLOCK MK2** DISPLAY BOARD CIRCUIT

**Fig.2: the upper board circuit has the six Nixie tubes, 44 of the 46 driver transistors plus the neons that separate hours/minutes/seconds and six blue LEDs to illuminate the Nixie tubes. The 27kΩ base resistors for the 44 driver transistors are strung between the two boards, ie, between CON4 and CON10 which are slotted edge connectors.**

Returning to Fig.1, nine of these 46 lines are driven directly from IC1's outputs RB1-RB3 (pins 5-7) and RB7-RB12 (pins 16-18 & pins 21-23). Since we don't have enough pins on the micro to drive all 46 segments, the other 37 are driven instead by the outputs of five 74HC595 serial-to-parallel shift registers, IC2-IC6.

These ICs are controlled by the micro using outputs RA1 (serial data output, pin 3), RB14 (serial clock, pin 25), RA0 (register latch, pin 2) and RA3 (output enable, pin 10). To change which Nixie digits are lit, IC1 delivers 5 x 8 = 40 bits of data on RA1, clocked using RB14, then brings RA0 high to update the outputs of IC2-IC6 simultaneously. It then immediately updates the output stage of the other nine control lines.

Each of these 46 lines drives the base of a high-voltage NPN transistor, Q1-Q46, via 27kΩ current-limiting resistors. Thus, with an output high at 3.3V, the base current is (3.3V-0.6V) ÷ 27kΩ = 0.1mA. The Nixie tubes draw about 1-2mA and the transistors typically have an $h_{FE}$ of around 40, so Q1-Q46 will be driven into saturation.

We're only using 37 of the 40 total output pins for ICs2-6 to drive Nixie segments. One of the remaining outputs (pin 7 of IC6) is unused while the other two drive the piezo buzzer (for the alarm function) and the blue LEDs mounted under the Nixie tubes. Thus the LEDs are under software control and can be easily dimmed or switched off if required.

## Power supply

The clock is powered from a 10-12V AC or DC supply, plugged into DC socket CON1. The ~180V DC used to drive the Nixie tubes is derived from this via a boost converter.

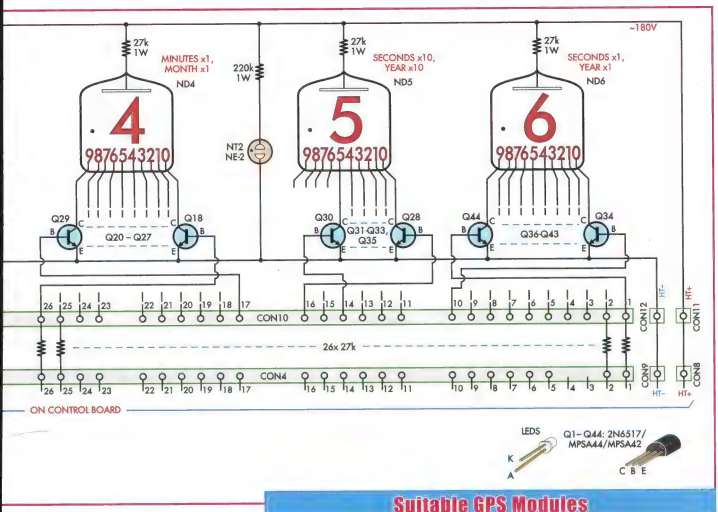
Bridge rectifier BR1 rectifies the AC or if a DC supply is used, provides reverse polarity protection. The resulting DC is smoothed with a 1000μF capacitor. This then feeds REG2, a 78L05 5V regulator, via a 47Ω/100μF RC filter.

The main purpose of the 47Ω resistor is to reduce the dissipation in REG2 when the filtered DC voltage is on the high side. It will dissipate up to 500mW with a 15V DC supply (eg, 12V AC rectified) and a 100mA draw on the 5V line. Under these conditions, REG2 will also dissipate 500mW, just under its 625mW maximum rating.

The output of REG2 is used to power a 5V GPS module, if fitted. It also charges a 1F super capacitor via diode D2, resulting in around 4.3V. Low-dropout (LDO) regulator REG3 derives the 3.3V for IC1 from this 4.3V input.

Thus, if there is a mains power failure, IC1 will continue to run off the charge in the super capacitor. By disabling all its outputs and dropping into a sleep mode, it can continue to keep time for many hours until the mains power comes back.

A second identical 3.3V LDO, REG4, is used to supply power for a 3.3V GPS module (if fitted) and also powers some of the ancillary circuitry such as the infrared proximity detector. This regulator is fed directly from the 5V output of REG2 so if mains power fails, the GPS and proximity detector will power down immediately. LK1




## Suitable GPS Modules

The following modules should be suitable for use in this project: GlobalSat EM-406A, Fastrax UP501 and VK16E. The Digilent PmodGPS and RF Solutions GPS-622R should also work but will not fit on the board unless mounted on top of a non-conductive spacer (which we recommend, anyway). Most other modules that will fit on the board should also be suitable but if they run off 5V, you will need to check that the serial output voltage does not exceed 3.6V.

Note that a few GPS modules are available with onboard RS-232 level converters and will deliver ±12V or similar on the TxD line. These **should not be used** in the Nixie Clock Mk2.

Note also that the GPS module isn't normally included with the kit but will be offered as an optional extra (or you can supply your own).

selects whether the GPS module runs from the 3.3V or 5V supply.

### HT supply

REG1 forms the boost converter and this runs directly off the rectified and filtered supply of around 12-15V DC. The 1nF capacitor between pins 3 and 4 ($C_T$ and GND) sets its oscillation frequency to around 33kHz.

When its switch output at pin 1 goes high, the gate of Mosfet Q48 is driven high via an emitter-follower buffer comprising NPN transistor Q46 and PNP transistor Q47. This buffer is required because pin 1 is an open-collector output and while it has good pull-up strength, a very low value resistor would be required to discharge the gate of Q48 quickly at switch-off. The buffer allows a higher value pull-down resistor (820Ω) to be used while keeping switching time fast.

When Q48's gate is driven high and it turns on, current flows from the ~12V DC supply, through inductor L1, through Q48 and to ground. This is effectively a short circuit across L1 and causes its magnetic field to rapidly charge. Its inductance, combined IC1's limit on the on-time, prevents this current flow from becoming excessive.

When Q48 is switched off, this magnetic field causes current to continue to flow in the same direction through L1 but the only path is then from ground, through ultrafast diode D1 and into the 10µF 250V capacitor. As a result, the voltage at this end of the inductor shoots up well above the 12V input. Current flow drops off as L1's magnetic field collapses, until Q1 switches on again and the process repeats.

IC1 monitors the voltage across the 10µF capacitor using a 390kΩ/2.7kΩ resistive divider and adjusts the duty cycle with which Q48 is driven to maintain 1.25V at its feedback pin (pin 5). This regulates the voltage across the 10µF capacitor to 1.25V x (390kΩ ÷ 2.7kΩ + 1) = 182V. This then supplies the Nixie tube and neon lamp anodes.

### GPS interface

CON7 provides the connections for

## Parts List

1 control (lower) PCB, code 19102151/NX15L, 144 x 64mm
1 display (upper) PCB, code 19102152/NX14U, 144 x 64mm
1 9-12V 250mA AC or DC plugpack
1 PCB-mount DC socket (CON1)
1 perspex case
6 1N14 Nixie tubes, 14-pin bases (ND1-ND6)
2 NE-2 neon lamps (NT1,NT2)
1 220µH 3A toroidal inductor (L1)
1 32.768kHz watch crystal, 10pF load capacitance (X1)
1 3-pin header with shorting block (LK1)
1 2-pin header, 2.54mm pitch (CON2)
1 5-pin header, 2.54mm pitch (CON3) (ICSP, optional)
4 1mm PCB pins (CON5,CON6, CON8,CON9)
1 6-pin header for GPS, 2.54mm pitch (CON7)
2 40-pin snappable machined socket strips (to make Nixie sockets)
1 mini 9-14V piezo buzzer, 7.62mm pin spacing (PB1) (Jaycar AB3459, Altronics S6105)
1 47-100kΩ LDR (LDR1)
2 PCB-mount horizontal momentary pushbuttons (S1,S2) (Altronics S1495)
1 GPS module with suitable connection cable (optional)
1 length double-sided tape (to affix GPS module)
1 plastic block, ~20 x 20 x 8mm (to affix GPS module)
1 250mm-length 1.5mm heatshrink tubing
4 25mm tapped metal spacers
4 12mm tapped male/female metal spacers
8 M3 x 8mm pan-head machine screws
12 4G x 12mm self-tapping screws (supplied with perspex case)
Assorted lengths of medium-duty hook-up wire
1 black card, 24 x 12mm

**Semiconductors**

1 PIC32MX170F256B-I/SP 32-bit microcontroller programmed with 1910215A.hex
5 74HC595 serial to parallel latch ICs (IC2-IC6)
1 infrared receiver (IRX1)
1 MC34063 switchmode regulator (REG1)
1 78L05 5V 100mA regulator (REG2)
2 MCP1700-3.3/TO 3.3V micro-power low-dropout regulators (REG3,REG4)
46 2N6517, MPSA42 or MPSA44 high-voltage transistors (Q1-Q44, Q51-Q52)
3 BC337 NPN transistors (Q46, Q49,Q50)
1 BC327 PNP transistor (Q47)
1 IRF740 400V 10A Mosfet (Q48)
1 13V 1W zener diode (ZD1)
1 infrared LED (LED1)
6 blue 3mm LEDs, clear lenses (LED2-LED7)
1 W02/W04 1.5A bridge rectifier (BR1)
1 UF4004 ultrafast 400V diode (D1)
1 1N4007 1A 1000V diode (D2)

**Capacitors**

1 1F 5.5V super capacitor
1 1000µF 25V electrolytic
5 100µF 16V electrolytic
1 10-100µF 6.3V tantalum or 10µF SMD ceramic
1 10µF 250V electrolytic
8 100nF multi-layer ceramic
1 1nF MKT, ceramic or polyester
2 22pF ceramic

**Resistors (0.25W, 1%)**

| | |
|---|---|
| 1 390kΩ | 1 2.7kΩ |
| 2 220kΩ 1W 5% | 1 820Ω |
| 2 100kΩ | 1 220Ω |
| 1 47kΩ | 2 180Ω |
| 6 27kΩ 1W 5% | 1 100Ω |
| 46 27kΩ | 1 47Ω |
| 3 10kΩ | 1 10Ω |
| 2 6.8kΩ | |

## Where To Buy A Kit

The Nixie Clock Mk2 will be available exclusively as a complete kit from Gless Audio. This includes the PCBs, all components, a programmed microcontroller, Nixie tubes and the case hardware. Kits should be available late February/early March 2015. Contact Gless Audio on 0403 055 374 or email glesstron@msn.com

a GPS module. There are two power supply pins – 3.3V/5V (depending on the module used) and 0V (GND). There are two serial pins, for transmit and receive, although the receive pin is not terribly important as most modules will send the required data without prompting. It's there for completeness.

Note that we're assuming that if a 5V GPS module is used, it has a 3.3V serial interface. That is typically the case – eg, the GlobalSat EM-406A requires a 5V supply and uses a serial signalling level of around 2.85V, while the VK16E can run off either 3.3V or 5V (or anything in between) and its TxD pin will produce a maximum voltage of 3.6V. Hence, we have no over-voltage protection for IC1's RxD input beyond the normal internal clamp diode. Refer to the panel on suitable GPS modules for more information.

The remaining GPS pin is for a 1PPS (one pulse per second) signal from the GPS module to the micro. This is used so that the seconds "tick" is accurately synchronised. However, should you use a module without a 1PPS output, the clock will still be synchronised to GPS time. It's just that it could be off by half a second or so. Most people will not care about this.

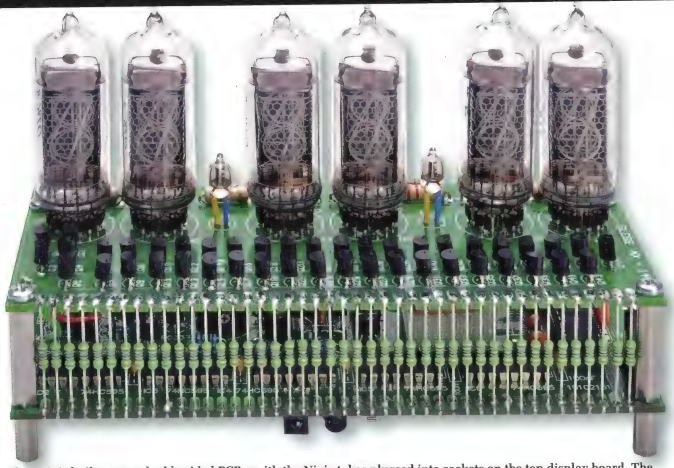
### Just wave for the date

Because it's inconvenient having to reach around the back of the unit to press a button when you want to see the date, we've fitted a simple proximity sensor. All you have to do is wave your hand in front of the unit and it will show the date for 10 seconds, then switch back to showing the time.

This is implemented using an infrared LED (LED1) and infrared receiver IRX1. LED1 has a series 220Ω current-limiting resistor and is driven directly from microcontroller output RB0 (pin 4). This is configured as a PWM output via the internal Peripheral Pin Select crossbar.

Periodically, based on a timer interrupt, this PWM output is enabled and driven at 38kHz with a low duty cycle. Some of the emitted infrared light pulses reflect back to IRD1 which detects this signal and its output goes low.

Depending on the proximity of objects to LED1 and IRX1, some of this light is reflected, resulting in a variable length output pulse. IC1 detects changes in the length of this pulse as indicating movement of nearby objects



**The unit is built on two double-sided PCBs, with the Nixie tubes plugged into sockets on the top display board. The GPS module, microcontroller and time-keeping circuitry are on the lower control PCB. Pt.2 next month has the full constructional details.**

and responds by showing the date.

Because there are no spare pins on IC1, the infrared receiver signal is connected to pin 25 via a 47kΩ resistor. This pin is also used to drive the SCK (serial clock) lines of serial latches IC2-IC6 however it's only driven when there is serial data to send. The 47kΩ resistor isolates the infrared receiver output during this time. The rest of the time, IC1 can sense the output level from IRD1.

Pins 2 & 3 of IC1 are similarly used for dual purposes. Both have resistive voltage dividers connected which are "overridden" when those pins are being used as outputs, to drive the latch clock lines of IC2-IC5 and the serial data lines respectively.

Pin 2 is used to monitor ambient light levels using LDR1 while pin 3 is used to (indirectly) monitor the mains supply voltage. Both are "read" by IC1 using its internal analog-to-digital converter (ADC).

For pin 2, as the light level drops, LDR1's resistance increases and so the voltage at this pin approaches the positive rail. This allows the unit to adjust the Nixie tube and LED brightness so it isn't overpowering in a dark room.

Pin 3 is connected to the filtered DC supply via an 11:1 voltage divider (ie, 100kΩ ÷ 10kΩ + 1). The voltage on this pin is periodically checked and if it drops below 0.64V, indicating less than 7V on the main filter capacitor, it is assumed that the mains power has failed (or been unplugged). In this case, IC1 turns off all its outputs and goes into sleep mode, to minimise the discharge rate of the 1F supercap.

The current drain in this mode is around 40μA and the real-time clock continues to run. At this rate, the clock should be able to keep time for a week or more until power is restored. IC1 "wakes up" every few seconds and checks the voltage on this pin again. Once it rises above 0.73V, mains power has resumed and so the chip switches back to normal operation.

Note that the LDR voltage is being read immediately after updating the data in latches IC2-IC5 so that, should the resulting voltage be low enough to effectively toggle the register latch inputs of these ICs, it will not change the state of the 40 output pins; they will merely re-latch the same data just sent.

## User interface

Besides the proximity sensor, which is used to display the date and snooze the alarm, there are only two pushbuttons to control the clock, labelled S1 and S2. These are connected to pins 14 & 15 of IC1 which are set up as inputs PB5 and PB6 with internal pull-up resistors enabled. The chip's Change Notification Interrupt feature is used to detect when a button is pressed, pulling one of these lines low.

These lines are also the programming interface (PGED and PGEC) and are connected to in-circuit serial programming header CON3. However, those functions are only operational when the unit is in programming mode, initiated by pulling pin 1 (MCLR) to a high programming voltage, so they don't interfere with button sensing.

There are a large number of functions available using these two buttons, including: setting the time and date (when a GPS module is not fitted), manually setting the time zone

# Determining Local Time Using GPS

If a GPS module is fitted to this unit, once it has acquired enough satellites, it automatically broadcasts the current time and date at its serial output pin. However, this time and date are in Universal Co-ordinated Time (UTC) which is almost identical to Greenwich Mean Time (GMT).

To figure out your local date and time, we need to know which time zone you are in and what your daylight saving rules are. Based on this information, we can then compute the local time. Once we know the time zone, this just involves adding the local time zone offset to the UTC time and date, then checking the local daylight savings rules and if applicable, adding the DST offset.

The tricky part is figuring out the current time zone. Once it has a fix, the GPS module provides its location as a latitude, longitude and altitude. To figure out what time zone you are in from this information, we need a map which defines all time zone boundaries and rules.

We initially considered using a free database called **tz_world**. This contains thousands of regions, defined by strings of lat/long pairs which make up their boundaries (as closed polygons) and each region is then associated with a time zone by name.

Unfortunately, **tz_world** is many megabytes. It could be loaded onto something like a Raspberry Pi or Beaglebone Black but even then, the calculations to go through those thousands of polygons (many of which are bounded by thousands of points) would take some time, even with a fast processor.

After some effort, we managed to extract enough information from this database to be useful and compress it into a much smaller size. The end result is a little under 100KB of data which contains enough information to determine whether a given lat/long is within any time zone for Australia, New Zealand, the UK, the USA, Canada or Western Europe.

After extracting this information, we simplified it as much as possible without compromising the accuracy. For example, we merged the zones for New South Wales, Victoria and Tasmania since they operate under the same rules and this eliminates the need to store the detail of the NSW/Victoria border. We also removed most of the coastal detail as it really isn't necessary. If you are using the Nixie Clock at sea, it will simply show time in the time zone for the nearest land mass.

We also found that **tz_world** defined straight lines or nearly straight lines (eg, most of the borders between Australian states) as a number of points in the polygon when we only really need to store the two end points. Removing the unnecessary intermediate points allowed further reductions in size.

## Delta compression

Finally, we applied a variable bit length delta compression to the data. Essentially, when a region is defined as "n" lat/long pairs, we don't need to store each pair separately. Rather, we can store the first pair, then the two-coordinate distance vector between subsequent pairs. Because each point bounding a region is usually quite close to the last, these "delta" values tend to be much smaller than the original lat/long values.

We store the values in thousandths of a degree. For example, Sydney is at 33.86°S, 151.2094°E (approximately). We store this as integers -338600,1512094 which takes approximately 48 bits of data space, ie, 6 bytes.

Say that is the first point in a region and the second is 33.85°S, 151.28°E. Rather than storing this second pair and using up another 6 bytes, we can store a delta of +0.01°,-0.0706° instead. Converting this to our integral format yields values of +10,-71. We can store delta pairs of up to ±0.1° in 16 bits, so this delta takes up 1/3 the number of bytes compared to the absolute location.

Similarly, deltas of up to ±0.0723° in lat/long can be stored in 24 bits (3 bytes, 1/2 the space) and up to ±1° in 32 bits (4 bytes, 2/3 the space). Very few co-ordinate pairs are further than 1° apart and on average, our scheme uses less than half the space required to just store the lat/long pairs.

Decompressing the data is simple and quick; the size of the next delta is stored in the first few bits of data, with the deltas themselves following. We then read these values and simply add them to the last decoded co-ordinate to get the next one.

## Time zone search

Once we had created the database of time zone boundaries, we needed a way to figure out if the current lat/long is within each region. That's not as simple as you might think given the complexity of some of these shapes. We need a way to determine whether a point is within a polygon by examining the points which define its vertices.

Before doing this though, we look at the lowest and highest lat/long values in the set of vertices and compare these to the current lat/long. If it's outside that bounding box, it can't possibly be within the time zone polygon and so we can skip that zone entirely.

Assuming that our lat/long is within the bounding box, we must then do the full polygon check. First we pick a random co-ordinate (lat/long) that's definitely outside the time zone boundary, using the bounding box as a guide. We then draw an imaginary line from our present position to that random position which we know is outside the time zone being considered.

If the current lat/long is within the polygon, that imaginary line will intersect the bounding line segments an odd number of times – most likely once, but possibly three or five times say. If we are outside

(with GPS fitted), trimming the crystal frequency, setting and viewing the alarm, turning the alarm on and off and changing various options such as 12/24-hour time and leading zero blanking.

To handle all these different cases, the unit detects long and short presses of the two buttons and also combination presses: both buttons pressed simultaneously, both buttons held down or one button held down and the other pressed. These various combinations allow the user to get into the different modes necessary to access the above functions.

## Piezo buzzer

Piezo buzzer PB1 is used to sound the alarm and is driven by NPN transistor Q50 from output Q0 of serial latch IC5. This buzzer can run off 9-14V. Since it's possible for the unfiltered DC supply to be slightly higher than this (depending on the plugpack used), 13V zener diode ZD1 is connected across the buzzer to limit the maximum voltage applied.

The current through this zener is limited by the drive capabilities of

it, the imaginary line will intersect the boundary lines an even number of times – probably zero, but possibly two (if our position and the random position happen to lie on opposite sides), or maybe four or more times, depending on the complexity of the shape.

So we go through each bounding line segment and test it for intersection with our imaginary line segment. This is done by computing the dot products, cross products and lengths of those vectors with reference to the signs and magnitudes of the results. This is hard to explain unless you are well-versed in vector mathematics but it's a relatively fast method to find whether the lines intersect.

For each intersection, we increment a counter. After having considered all point pairs in the time zone boundary polygon, if the counter value is odd, we must be within that time zone and we need not consider any of the others. We then look up its rules (offset, daylight savings) and apply them to the UTC time/date to get and display the local time.

If we go through all the time zone regions and we're not within any of them, the time zone offset must be entered manually via the pushbutton interface. Alternatively, should your time zone rules change, you can override this automatic detection using the same setting to prevent the clock from showing the wrong time.

## Nixie Tubes: How They Work

Nixie tubes work on the same principle as the simple neon indicator. A neon indicator consists of a small glass tube filled with inert neon gas and containing two metal electrodes. When a sufficiently high voltage is applied between the electrodes, the gas around the negative electrode (the cathode) ionises and envelops the electrode with an orange glow.

The voltage required for ionisation of the gas is dependent on the electrode spacing and the temperature. Typically, it is more than 80V for small neon bulbs and more than 150V for Nixie tubes. In practice, higher voltages are used, with a series resistor to limit the discharge current to a safe value.

Two small neons are used in this clock design, between the hours and minutes and between the minutes and seconds tubes.

A Nixie tube has a see-through metal mesh anode at the front and 10 different shaped cathodes (0-9) behind the anode, each being terminated to a different wire lead or pin on the tube. The number-shaped cathodes are not necessarily placed in direct order behind the anode but are placed to give minimum obstruction of each digit by the ones in front of it.

The anode is connected to +HT via a current-limiting resistor and the particular cathode is pulled down to 0V when it is to be lit. By the way, "HT" is old-timer talk for "high tension" or high voltage.

### New old stock

Nixie tubes are no longer manufactured. Instead, they are now available as "new old" stock, originally made in either the USA or the former USSR. The ones used in the Nixie Clock described in this article were made by RCA (USA) in February 1954 – ie, over 60 years ago.

The Nixie Clock is built into a clear acrylic case. Pt.2 next month has the full constructional details.

## How Quickly Will You Get A GPS Fix?

When a GPS module is powered up for the first time, it starts searching for satellite signals. Normally, there are somewhere between about 10 and 14 GPS satellites overhead at any one time however if parts of the sky are occluded (eg, by a roof), then the receiver may not be able to pick up all the signals.

In addition to "finding" the satellites, the receiver module has to gather the "ephemeral" data which is slowly broadcast by those satellites. This will normally take at least half an hour. This data changes slowly, so if the receiver has a recent copy of the data, it won't need as long to get enough data to begin operation. With a "hot start", it can be up and running in seconds.

If, however, it has never been powered up before or if it has lost power for long enough for its RAM back-up battery/capacitor (if fitted) to discharge, it can take quite some time to get a fix. How long depends on how clear a "view of the sky" the receiver has.

In an indoors location, some receivers will never get a fix unless they already have a relatively up-to-date version of the ephemera stored in RAM. In other words, you might find that the module will not get a fix until it has been taken outdoors for a few minutes (powered up, obviously) and then brought back inside. It may then be able to maintain a good fix with the weak signal available at that location. Sometimes, putting the module next to a window for a little while will do the trick.

This is why many GPS modules have an onboard RAM back-up battery, so they can keep track of time and ephemeral data while powered down. Some do not have this feature though – presumably, the assumption is that they are part of a battery-powered instrument and so are never without a power source.

You don't need to use a GPS module with an on-board battery in the Nixie clock. Most modules which don't have a battery will have a power pin which can be connected to a back-up power source. This may be labelled VDD_B or similar (check the data sheet). On the UP501, this is pin 5. (The UP501B has an onboard battery and pin 5 should be left unconnected).

Assuming that a 3.3V supply is suitable (which is true for the UP501 and probably most other modules), you can simply wire this up to pin 2 of CON3, the ICSP header. VDD_B will then be powered from the onboard 1F supercap and so the ephemera will be preserved for many hours (probably days or weeks) without mains power. The GPS module will then be able to get a fix relatively quickly when the power comes back on.

Note that one reason that the ephemera is required is that GPS time differs slightly from UTC. At the time of writing, the difference is about 12 seconds and this is due to leap seconds having been used since the GPS system was set up. So the receiver needs this data not only to get a position fix but also to report accurate time.

Note also that in some buildings, you may need to keep the Nixie Clock near a window in order for it to get a good fix at all.

Q50. Its base current is around 0.4mA and with a typical hFE of 150 it will therefore sink about 60mA if ZD1 conducts, about 30mA through PB1 and 30mA through ZD1.

The blue LEDs on the upper board are powered via NPN transistor Q49 which is driven from the Q0 output of serial latch IC6.

## Software

The software for this unit, while fairly complex (to handle all the various modes), is straightforward. Its main job is to set up the real-time clock, wait for a second to pass, then drive the appropriate Nixie segments to display the correct time. Simultaneously, it monitors the GPS serial and 1PPS signals for time/date updates and also monitors the pushbuttons, LDR, infrared receiver and supply voltage.

The most complex part of the software involves handling time zones correctly. Simply getting the time from a GPS receiver is quite straightforward. It's just a matter of parsing the text messages which are sent several times per second and extracting the time field. However, this gives Universal Coordinated Time, which is akin to Greenwich Mean Time. And we want the clock to display local time, which is only the same as GMT in the UK when daylight saving is not in effect.

These days we tend to expect clocks to take care of things like daylight saving time. After all, modern computers and phones always show the correct local time, if set up correctly. We can do the same thing using a GPS module since we can figure out the time zone and daylight savings rules based on the present location.

But this is a difficult problem because there are so many different rules and the various boundaries where they change are not always straight lines! For example, consider people who live in or near Coolangatta, on the zig-zagging New South Wales/Queensland border. While NSW and Queensland are in the same time zone, NSW observes daylight saving while Queensland does not.

Depending on which street a house is on in Coolangatta, the (official) local time could vary by an hour. So we need to figure out which side of the border the unit is on to display the correct time year-round.

Basically, if you are using a GPS module for time, this is all handled automatically. The calculations are accurate to within a few tens of metres so unless you live right next to the border and are very unlucky, the time shown should be correct. If you're interested in the details of how the software does these calculations, refer to the "Determining Local Time Using GPS" panel.

## Physical layout

As mentioned earlier, the Nixie Clock is built on two PCBs, with a few wires and 44 resistors connecting them together. The lower PCB has the power supply and all the control circuitry (including the GPS receiver, if fitted), while the upper PCB has the Nixie tube sockets, neon indicators, blue LEDs and most of the high-voltage transistors.

In fact, the upper PCB is almost identical to that used in the original 2007 design. It's the control circuitry on the lower board which has been completely revamped. Both boards are mounted on spacers within a clear acrylic (Perspex) case to provide insulation so that you can't get a shock from the 180V Nixie anode supply. The Nixie tubes protrude through holes on the top, while the power connector and pushbuttons are accessible through holes at the rear.

We'll get to the construction of the two PCBs and the final assembly into the case in Pt.2 next month. SC

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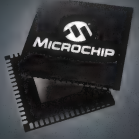


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# SERVICEMAN'S LOG

## Transforming a Roland Cube-120XL amplifier

**SILICON CHIP staff member Nicholas Vinen recently got roped into fixing a Roland Cube-120XL BASS amplifier. Unfortunately, it wasn't all plain sailing.**

A few months ago, my friendly neighbour Kevin (who knows that I'm "a bit of an electronics/hifi nut") showed me his new Roland Cube-120XL BASS amplifier. This is a 120W bass amplifier with an integrated 300mm diameter speaker (with coaxial tweeter) plus an effects unit in a sturdy portable case.

Kevin's a musician and he bought the Roland gear to amplify his drums. According to him, it worked a treat and I have to admit that it looked quite impressive, with a bunch of control knobs that allowed him to tweak the sound to his liking. What's more, it was a bargain as the store he bought it from was closing down and he got it for a fraction of the usual price.

Recently, though, he approached me with some less cheerful news. He was playing a gig and apparently somebody plugged his bass amplifier into a dimmer switch socket. Nobody noticed what had happened until all the power went out and when they got it back on, the amplifier was as dead as a dodo. "It'll just be a fuse" the perpetrator informed him, rather sheepishly.

Well, that's what I said too, when he told me what had happened. So I said to bring it over to my place; I figured it would be a 5-minute job, maybe even less if the mains fuse was externally accessible.

Unfortunately it wasn't, so we removed six screws from the unit which then allowed us to lift the whole control unit, including the amplifier and most of the power supply, out of the cabinet. This revealed seven or eight fuses, one of which was clearly the mains fuse. This fuse was mounted on a separate board in the corner and it was intact.

A continuity check of the other fuses indicated that they were OK as well. So why was the unit totally dead?

I then noticed a pair of wires running from the mains input board, through a wooden baffle and into the guts of the amplifier. There was also a bunch of wires running back out and connecting to the main amplifier PCB. Presumably these wires went to either a mains transformer or to a switchmode supply.

I couldn't immediately see how to get inside the rest of the case so I measured the resistance between the two mains wires going to the amplifier (by unplugging the spade lugs) and got an open circuit reading. Uh-oh – if the power supply was a traditional type with a transformer, it wasn't looking very good as that would suggest that the transformer primary had no continuity, most likely due to its thermal fuse opening.

We eventually figured out that in order to get to whatever was behind the baffle, we had to remove the front grille and the speaker driver. This turned out to be straightforward – just four screws hold the grille on and eight fix the driver in place and compress its foam surround to form a seal. The two wires to the driver were then unplugged (spade lugs again) so that it could be completely removed.

At this stage, it wasn't looking too good because all that was left inside was a large E-core transformer that was welded to a rather large baseplate. We removed its four mounting screws, unplugged the polarised header connecting its secondaries to the main PCB and extracted the transformer for a closer look.

Further tests confirmed our worst fears. The transformer had clearly gotten very hot (undoubtedly due to running off the dimmer) and its thermal fuse had gone. So it was bye-bye to the transformer; so long and nice knowing you. All very elementary, my dear Kevin.

Now the real detective work began, as there was nothing marked on the transformer to indicate its power rating, its output voltages or even its lead configuration. However, based on the 5-pin header and the layout of the main board, it didn't take us long to

figure out that there were two pairs of secondaries with a common centre tap.

One pair drove a bridge rectifier and its associated filter capacitors and this then fed the regulators to run all the mixing and control circuitry. The other secondary fed a separate, larger rectifier which then charged a large, high-voltage DC capacitor bank to run the main power amplifier. We could then guess from the 78L12 and 79L12 regulators (SMD) used in the preamplifier section that the low-voltage secondaries were probably 12VAC.

The problem now was figuring out what voltage the power amplifier ran at. There were no markings on the board itself or anywhere else in the unit. In fact, marked voltages of any sort were conspicuously absent. This remained true when we managed to find a service manual for the previous model, the CUBE-100 BASS, floating around on the internet.

Fortunately, this is a very similar unit to the CUBE-120XL BASS. It's the same size and judging by the diagrams in the manual, the newer design is closely related. But nowhere in the service manual did it mention the transformer secondary voltages or any voltages anywhere in the circuit or on the PCBs! Nor could we find any test points.

In the end, I resorted to three different techniques to figure out what voltages the now dead transformer was originally putting out. First, I measured the inductance of the two sets of secondary windings using an LCR meter. This gave readings of 10mH for the low-voltage winding and 28mH for the high-voltage winding.

Basic theory tells us that the inductance is proportional to the square of the number of winding turns, while the output voltage is directly proportional to the winding turns. So, working on the assumption that the low-voltage secondary originally provided a 12V output, this allowed me to calculate that the high-voltage secondary should have given about 12VAC x $\sqrt{(28mH \div 10mH)}$ = 20VAC.

The second method I devised was to look at the components surrounding the amplifier section in the circuit diagram of the older CUBE-100 BASS model. This uses a TA2022 class-D switching amplifier chip from Tripath and while I couldn't see the chip details on Kevin's unit, it certainly looked like the same type. This is a stereo monolithic amplifier and in this case, it drives the speaker in bridge mode.

This means that it doesn't need a very high supply voltage to develop a decent output power.

Like most such chips, the TA2022 has over-voltage protection and the switch-off threshold is set by a pair of external resistors. On the CUBE-100 BASS circuit, these are 180kΩ and using the formula provided in the TA2022 data sheet of $R_{VPPSENSE}$ = ($V_{PP}$ - 2.5V) ÷ 138µA, I calculated the over-voltage threshold to be 180kΩ x 138µA + 2.5V = 27.34V.

This suggests that the main power supply operates at no more than about 25V which would mean a transformer secondary of 17VAC or less.

I wasn't able to see the value of these resistors on the CUBE-120XL BASS board, so I simply figured that they would have bumped up the supply voltage slightly to give the extra 20W of power. So the 20VAC figure calculated earlier seemed quite plausible.

## Speaker impedance

The third method involved calculating the impedance of the speaker. Its DC resistance is about 6Ω which suggests that it is an 8Ω driver (the DC resistance is generally about 2/3 to 3/4 of the AC impedance).

**Items Covered This Month**

- New transformer for a Roland cube-120XL BASS amplifier
- Wrecked Wharfedale loudspeakers
- Sansui A222 amplifier
- Fender guitar amplifier

I then calculated that to deliver 120W into 8Ω in bridge mode, you need supply rails of at least ±24V. Taking losses into account, this would give a maximum output swing of around ±22V or a 31VAC RMS full-scale sinewave across the driver for a power output of $31V^2 \div 8\Omega = 120W$. This would require a transformer with a secondary output of at least 17V but probably slightly more because of ripple on the supply capacitors.

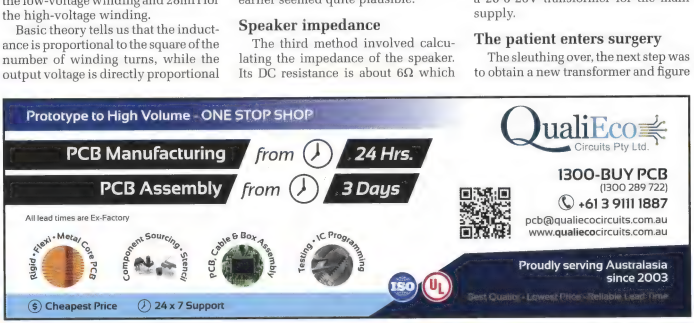
You can estimate the capacitor bank ripple using the formula $\mathbf{V = I \div (f \times C)}$, where **I** is the load current, **f** is the recharge frequency (twice the mains frequency or 100Hz) and **C** is the capacitance (5700µF on each rail). With a 40V supply, the load current will be around 3A at 120W and these calculations give us a ripple figure of ~5V.

That means DC supply rails of at least ±27V and to get that we need a secondary voltage of 19.5VAC. So 20VAC is about right if we're to avoid clipping until the output power reaches 120W.

All three figures agreed so we needed a 20-0-20V transformer for the main supply.

## The patient enters surgery

The sleuthing over, the next step was to obtain a new transformer and figure

# Wrecked Wharfedale Loudspeakers

What could possibly wreck a pair of 150W Wharfedale loudspeakers? This fault was a real mystery but M. H. of Woolloongabba, Qld eventually tracked it down. Here's what happened . . .

A friend recently contacted me one evening, somewhat distraught. He had just turned on his Yamaha A-1020 hifi system to listen to digital radio only to be met with a loud bang and the pungent smell of burning.

Suspecting a catastrophic electrolytic capacitor failure, I suggested that he drop the amplifier over that weekend. In the meantime, I downloaded the circuit and familiarised myself with the details of this very nice unit. Although this 125W stereo amplifier is now well over 20 years old, its distortion figures and grunt made it well worth repairing.

When the lid came off and the accumulated dust had been brushed away, there was no sign of an exploded electrolytic, or of any burnt components for that matter. What's more, the fuses were completely intact so it was all rather puzzling.

A simple ohmmeter check showed that the output transistors at least hadn't gone short circuit. Given the amplifier's age, my next step was to check all the electrolytic capacitors for high ESR but they all came up fine. Eventually, with nothing left to check, I applied power. The supply voltages all came up within specification and nothing melted.

After a few moments pondering, I switched off, connected a pair of old speakers to the amplifier and fed a sinewave signal from a signal generator to the inputs. When I switched the amplifier on again, I was greeted with pure tones in both channels.

The fault was clearly not with the amplifier, so what went bang and caused a burning smell? There was nothing for it but to visit my friend's place later that week to investigate further.

When I arrived, I went straight to the nearest Wharfedale speaker sitting high on a shelf. I needed a chair to reach it but even while unhooking the speaker cable, it was obvious that the speaker was the source of the burning smell. Popping off the front grill confirmed that the main speaker cone had jammed solid, no doubt the result of a thoroughly burnt-out voice coil.

Curious, I moved the chair and climbed up to the other speaker. One sniff confirmed that it had suffered the same fate as its companion. So that explained the burning smell but what drove the amplifier so hard as to destroy a pair of 150W speakers?

My friend said that the system was only ever used to listen to digital radio but given the size of the room, the volume control was never advanced beyond about one third. His digital radio is a medium-sized shelf-mounted DOTEC BC76183 with an entirely inadequate internal speaker. However, my friend had acquired a stereo 3.5mm plug to dual-RCA lead and had connected the radio's speaker output directly to the amplifier's auxiliary (AUX) inputs.

At that stage, I decided to take the radio back home for a closer look. I set it up on the bench, hooked it up to a scope and immediately spotted a +5V DC shift on the 1V peak-to-peak audio output. But things really got interesting when you first turned the radio on. At switch on, the output voltage stepped from 0V to -1V, sat there for a while, then exponentially ramped up to +5V in about 100ms. A few seconds later, the audio modulation arrived.

In spite of this, the digital radio had been connected to the Yamaha amplifier for more than a year without any problems. This amplifier has a particularly long delay before the internal protection relay closes, so the radio's output stage had usually settled down well before the speakers were connected (provided, of course, that the radio was turned on first). On the last occasion however, it appears that my friend had turned the amplifier on first and when he realised that there was no

out how to mount it. However, unless I had a custom transformer made up with 20-0-20V and 12-0-12V windings, it would in fact be necessary to install two new transformers.

The old transformer was mounted in the corner, so as to not interfere with the massive magnet and the voice coil on the speaker driver. One of the new transformers would have to go there, while the second would have to go in the opposite corner.

For some reason, power transformers with 20V outputs are not common, the usual choices being either 18-0-18V or 25-0-25V. I settled on a 160VA 18-0-18V toroidal transformer as the next one up would risk overheating and possibly damaging the amplifier.

Toroidal transformers usually have pretty good regulation anyway and 160VA is more than enough given the efficiency of the Class-D amplifier. So it would give Kevin most of the original 120W that his Bass Cube possessed. Besides, he told me, "I never really go past three on the volume control anyway", which struck me as rather strange since a lot of musicians like to turn theirs up to 11!

Mounting this new transformer in the new position was a bit tricky, mainly because the M5 x 50mm screw supplied with it was only just long enough to attach it to a thin metal panel. This case is made from MDF though and the baffle is about 25mm thick.

I probably should have gone out and bought a longer screw but I was running out of time. So I simply drilled a 5mm hole and then enlarged the outer portion of it to around 10mm using a stepped drill bit, to allow the screw head to be recessed into the panel. That did the trick (just) and the remaining 10-15mm of MDF seems quite strong and will hopefully hold the transformer in place even if it gets a few knocks (Kevin promised he'd be careful with it just in case).

I also drilled a series of 3mm holes down the middle of the baffle and used two Nylon machine screws to mount a terminal block strip (nine pairs) on the inside, between where the two transformers would go. Once again, I had to recess the heads even though they were the longest Nylon screws I could easily get.

Five terminals on the block were

program, turned the radio on, only to be greeted with the aforementioned loud bang and the burning smell.

Basically, the amplifier had been presented with an enormous input signal at about 2.5Hz. The amplifier is fully rated down to 20Hz so it had no problem reproducing at least some of this waveform. But I was deeply suspicious. A single half cycle at 2.5Hz should have produced a loud thump from the speakers but certainly shouldn't have completely destroyed them. Something else just had to be going on.

Out of interest I checked another digital radio. It was nowhere near as bad as the first but it could still give the speakers a good thumping if allowed.

Curiously, this one was worse at switch off rather than switch on. On the other hand, an iPod was entirely well-behaved. Clearly, the digital radios are designed to operate into headphone or speaker loads, not the effectively open circuit inputs of an amplifier.

My friend restored the amplifier to its rightful place, replaced the speakers, and bought a new digital radio. For good measure, I added a pair of 100Ω load resistors across the radio's outputs. This new configuration performed perfectly but I remained totally sceptical that the radio's output stage thump was the real cause of the problem.

My friend didn't want to see his old digital radio again so I set it up with a small amplifier in my office to provide background music. It performed satisfactorily for many months until one cold morning when, at switch on, the speakers gave a very loud thump and were driven hard with a raucous tone that I guessed to be about 30Hz. The tiny amplifier couldn't deliver enough power to damage the speakers this time but the noise was impressive nonetheless.

Turning the digital radio off and then on again cleared the problem and it could not be persuaded to return. So finally, the culprit had been exposed as an intermittent instability problem in the digital radio. It only occurred occasionally but when it did, it fed an enormous low-frequency signal into the amplifier.

That accounted for the reported load noise just before the voice coils were driven to total destruction and went silent forever. Given that both channels were equally affected, I suspect the actual problem lies deeper in the radio's circuitry than just the output stages. However, with the plummeting costs of digital radios, it's quite impractical to waste time tracking down such an intermittent fault.

As a result, the old radio was scrapped and replaced with a later model. It had taken many months to get to the bottom of the mystery but at least I now had the satisfaction of knowing the real cause of my friend's burnt-out speakers.

~WITH PLUMMETING COSTS OF DIGITAL RADIOS...

used for the transformer secondary connections and two for the mains, with a gap of two terminals between them. As well as mounting holes for the strip, I drilled four holes on either side to allow cable ties to clamp all the wires down once they were in place, so nothing could come loose. After all, there's no earthed metal chassis here, so it was necessary to ensure the wiring cannot come loose and possibly short the isolated low-voltage and high-voltage sections to each other.

During this work, I also realised that the large baseplate that the original mains transformer was mounted on is not earthed, despite being accessible from the low-voltage side of the baffle. In any case, servicing this unit while it is plugged into the mains is hazardous as there are live, uninsulated mains conductors running around the edge of the control module PCB. So basically, you'd be crazy to open it up while it was still plugged in.

Anyway, with the main transformer now in place, I wired it into the terminal strip. We then set about mounting the 12-0-12V transformer which would run the control and mixing circuitry. This is one I happened to have lying around and was far larger than required for the job but it was replacing a larger transformer anyway and the CUBE BASS (or is that BASS CUBE?) is so hefty that it didn't really matter.

This transformer was mounted in place of the original transformer. As a result, we were able to re-use one of the existing mounting holes and simply drilled another and used two M4 x 25mm machine screws to hold it in place. At the same time, we fitted a thin sheet of MDF in place to cover up the hole that used to be covered by the old transformer's mounting plate.

The two transformer primaries were then wired together using the terminal block, as were and secondary centre taps. We then cut the primary and secondary leads off the old transformer and wired them onto the other side, fed the wires back through the grommet in the baffle, tied everything down neatly and plugged it all back together.

Having done this, we decided to check the voltages before re-connecting the transformer secondary outputs to the control board. We still needed the control module in place however, as the mains input board is part of it and it would be quite hazardous to power the transformers up otherwise. So we left the power plug for the main PCB disconnected and also left the speaker driver disconnected.

Before powering it up, we checked that there was proper isolation between the two mains conductors and all the low-voltage secondary connections. That was all OK so we switched it on and by reaching through the hole for the speaker driver, probed the terminal block with a DMM.

The voltages all seemed correct, being 13VAC for the 12V outputs (unloaded) and 19VAC for the 18V

# Sansui A222 stereo amplifier

Despite its age, G. P. of Ky Valley, Victoria recently repaired a 1970s Sansui A222 stereo amplifier at the owner's request. Here's how he tracked down the faults . . .

I have been a TV/electronics technician all my working life. In that time, I have read hundreds of electronic magazines, going right back to "The Serviceman who Tells" in *Radio and Hobbies* and continuing right through to the present day. This is my first contribution to this column, so here goes!

My story involves a repair to a Sansui AU222 stereo amplifier. The unit in question is nearly 40 years old now but is well-built and the owner has a sentimental attachment to it. I was not given any specific complaint but just asked to fix it.

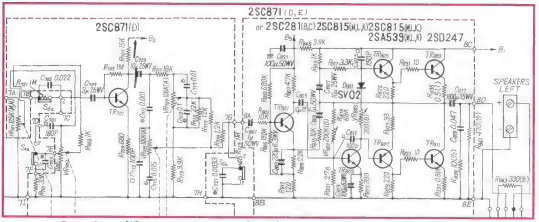
Along with the amplifier, the customer also supplied the instruction book. This was also the service manual with schematic and PCB layouts. It really was a pleasure to service in those days!

On removing the cover, I noticed that it had been repaired several times previously as it had several new electrolytic capacitors and some relatively fresh solder joints. I checked all the fuses which proved to be OK, so I turned it on and checked the DC voltages around the output stages. These all seemed to be correct.

Next, I connected my test speakers and tried a "blurp" test on one of the auxiliary inputs. This indicated that both channels were working, at least to some extent. I then noticed a fairly high level of noise (hiss) from the left channel with the volume control at zero.

Using a scope, I traced the noise back to the collector of TR701 which is the tone control preamplifier. Closer inspection then revealed that C707, its base coupling capacitor, was physically leaky, with associated discolouration on the PCB. Cleaning up the PCB and fitting a new 3.3µF electrolytic cured the noise problem.

The next step was to carry out a signal test. I fed a 400Hz sinewave into both Aux1 inputs and used the scope to check for gain




**Sansui amplifiers were very popular. This circuit is interesting because the amplifier had a quasi-complementary output stage, AC-coupled negative feedback and AC-coupling to the loudspeaker via a 1000µF capacitor. Also note the rudimentary preamp stage involving TR701.**

outputs. We also checked the phasing and confirmed that the two groups of outputs were in-phase, ie, the adjacent 12V and 18V outputs had about 6VAC between them. This doesn't really matter but it minimises the voltage across adjacent pins. (Me? Compulsive? Nah!).

Anyway, we then had to bite the bullet and having disconnected the mains, we plugged the secondaries back into the control module, crossed our fingers and switched it back on. We were greeted with a display of many flashing lights which at first I thought were indicating some sort of error but then we realised that I had simply bumped the controls and rotated the knobs during the repair job; a quick twiddle had everything back to normal.

Once again we switched it off and now, confident in our repair work, plugged the speaker driver back in and re-mounted it in the case. A final check with various signal sources showed that it was all working normally. Phew!

Kevin was very pleased and swore to me that he would never let anybody else plug it in for him again. We may need to open it up again soon anyway; now that there are two transformers, the original fuse may be inadequate to cope with the initial surge current at switch-on so it could fail and we may therefore need to up-rate it.

I also would like to get a longer mounting screw for the toroidal transformer and attach it with a metal plate or large washer under the head so that it's a bit more secure. But for now he's chuffed and I'm glad that his toy, err, serious bit of work gear, is back in working order.

## Fender guitar amplifier

Where the dickens is Korweigu-boora? Well, its in Victoria, not far from Ballarat and that's where R. R. ran into trouble with a valve guitar amplifier. Here's what happened . . .

Recently, one of my favourite guitar amplifiers, a 15W all-valve Fender Blues Junior, started playing up. This amplifier is just the right size for practice and playing at home and had given me many years of excellent trouble-free service. And then, about a month ago, I was practising a new tune at home (Stevie Ray Vaughan's Texas Flood) when the amplifier starting making occasional crackling noises.

I hadn't changed any of the valves in this amplifier since I'd purchased it four years ago. Because of this, I decided to purchase a complete new set and wait until they turned up before troubleshooting the crackling problem. In the meantime, it wasn't too bad so I would keep using it.

Unfortunately, things rapidly went from bad to worse and within a couple of days it had progressed to no output

and distortion. This showed that the right channel had only about half as much the gain as the left and the fault seemed to be in the power amplifier circuitry. As a result, I carefully went over the right-channel amplifier, checking the capacitors and voltages, freeze spraying and heating but to no avail

## Comparison checks

After spending a fruitless hour on this, I began doing comparison checks between both amplifiers and eventually discovered that the fault was actually in the left channel. Capacitor C809, the negative feedback coupler, was open-circuit, thus giving the left channel too much gain in comparison with the right.

Replacing this capacitor cured the problem, with both channels now having equal gain. Further testing revealed no more problems, so the unit was cleaned, reassembled and returned to its owner.

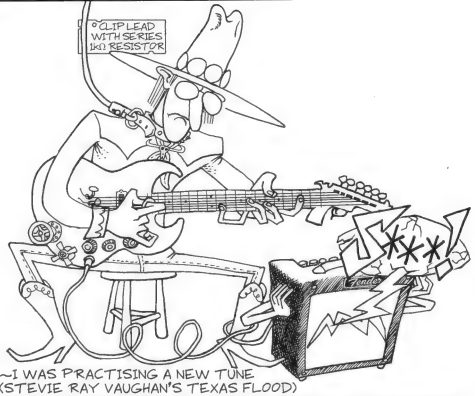
It just goes to show that in servicing it is all too easy to adopt too narrow an approach and not take in the full picture. It's also worth noting that if I had opted to take a "shotgun" approach and has simply charged in and replaced all the electrolytics at the start, the job would have been done in half the time. But then I wouldn't have had a story to tell!

at all. There was nothing for it but to put it aside and wait for the new valves to arrive so I could start work on it.

This amplifier uses three 12AX7s for the signal processing and two EL84s in a transformer-coupled push-pull output stage. The first 12AX7 (V1) uses one triode for the input preamplifier (with a gain of approximately 30), while its second triode drives the tone control stages. Further amplification is then provided by one triode of the next 12AX7 (V2), while the third 12AX7 (V3) acts as the phase splitter for the power output stage.

As with all valve amplifiers, it uses quite high voltages for the plate supplies. The 12AX7 plates run off a 250V DC supply while the output stage plates run from a 300V DC supply, so caution is necessary when fault-finding valve amplifiers.

Eventually, the new valves arrived, three JJ 12AX7s (noted for their high




gain and low microphonics) and a matched pair of JJ EL84s. It is important when dealing with push-pull output stages in valve amplifiers to use matched pairs of valves. This not only ensures minimal crossover distortion but also ensure that the valves age at much the same rate.

Anyway, the new valves were fitted and the rear cover removed to expose the chassis parts. I then connected my audio oscillator to the input, set all tone and volume controls to midway and switched the unit on. There were no puffs of smoke or loud bangs but there was still no sound from the 30cm speaker included in the amplifier's cabinet, so it wasn't the valves that were at fault.

And so it was onto phase two of the troubleshooting process. Just as with semiconductor fault-finding, the very first thing I look at is the power supply rails. I checked all the low-voltage, heater and HT (high tension) supplies but these all appeared to be correct. I then began checking the voltages around the valves and other active components and this was where things got interesting.

V1A, the tone-control driver triode of the first 12AX7, had a plate voltage of 250V DC (at pin 1 of its socket) and a cathode voltage of 0V DC. However, the circuit showed that there is a 100kΩ resistor in V1A's plate circuit and also a 1.5kΩ feedback resistor in the cathode ground path. So the above measurements implied there was no current flowing through this triode.

For those of us versed in the black art of thermionic valve technology this will come as no surprise – plate resistors fail routinely in valve circuits. A common failure mode is for the plate resistor to go high, so I quickly switched off, discharged the power supply capacitors (I have a clip lead with a series 1kΩ resistor attached for this purpose) and checked the plate resistor, expecting to see a figure in the megohm range.

To my surprise the resistor measured perfectly OK. However, experience with evil devices like thermionic valves

*continued on page 104*

**Servicing Stories Wanted**

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# How to measure SPARK ENERGY in an ignition system

**Modern car ignition systems are reputed to deliver very "hot" sparks but how do you measure their energy? And which system is better: CDI or transistor-assisted ignition? And what about multi-spark CDI systems? This article discusses how the energy of sparks can be measured, as a prelude to a Spark Energy Meter presented elsewhere in this issue.**

By Dr Hugo Holden

**Knowing the energy intensity of an ignition spark** – and that they are equal across all cylinders – is an essential part of engine service. But how can you tell?

In general, a spark is best defined as plasma, with the physical properties of a gas and the electrical properties of a metal conductor. Plasma is an ionised gas stream where the atoms' electrons have been mobilised by the applied electric field and are free enough to carry an electrical current.

A spark's ability to ignite a gas mixture is related to its peak temperature and this is proportional to the spark's peak power. Since a spark has a fairly stable voltage drop, the peak power is also related to peak spark current.

A spark initially starts in the gas ionisation phase where a fine streamer of ionised gas forms between the spark plug's electrodes. This creates an increasingly hot electrically conductive pathway and helps to excite adjacent gas molecules and mobilise their electrons until a spark is fully established.

A fixed amount of energy delivered to the spark over a shorter time frame results in more heating or a hotter spark than if that same amount of energy is delivered over a longer period.

This is not dissimilar to delivering electrical energy to a resistor, although unlike a resistor the spark plasma existing between two electrodes tends to adopt a fairly stable voltage, largely independent of the current. (It is actually a negative resistance.)

One way to assess a spark's gas ignition ability is to divide the spark's burn time energy in Joules by the time over which this energy is delivered, in seconds. This is the spark's pulse power or SPP which has units of Watts and this can be used as a parameter which indicates a spark's ability to ignite gases.

In practice though, measuring the individual spark's energy alone is a very useful measurement regardless of the spark's duration.

## Spark sustaining

In a typical automotive set-up, with the engine running, the spark plug voltage drop during the spark burn time in the combustion chamber is around 1000V but this varies, depending on the spark gap, mixture, etc.

In air though, a spark plug typically has a voltage drop of around 500V to 600V. Once established it has similar electrical properties to a zener diode. Hence the industry standard electrical equivalent or "dummy spark plug" is a 1000V zener diode.

In systems with a mechanical distributor, the voltage drop of the distributor's air gap spark is around 500V so the ignition coil experiences a total constant voltage drop of about 1500V during the spark time. This is a low value compared to the ignition coil's open-circuit output voltage; often as high as 30kV to 40kV for some coils.

## Spark ionisation energy versus spark burn time energy

In general there are two aspects or phases to the spark's energy. The initial early phase is the establishment of the spark or initial ionisation the gases between the spark plug's electrodes. The voltage has to climb high enough to ionise

a fine streamer of gas between the spark plug's electrodes and initiate the spark.

The capacitance of the ignition coil secondary winding and the HT wiring set-up and the spark plug body (the total being around 70pF) must be charged to a high voltage very briefly prior to spark ionisation. This could be 10kV or more.

When the spark strikes, usually after less than a microsecond, these system capacitances are rapidly discharged down to a low voltage of around 1000V with very high peak currents in the order of 50 to 100A (unless there is added series resistance to reduce this peak current).

The capacitance is suddenly shunted into the low impedance when the spark strikes. The electric field energy of $\frac{1}{2}CV^2$ is generally in the order of 3.5mJ (millijoules) with a 70pF capacitance charged to 10kV prior to the spark's ionisation.

This energy is not the energy of the "spark burn time" which is the longer phase in which the spark is seen to exist by an observer.

The ionisation phase is probably important in overcoming fouled plugs and initiating combustion in some cases.

A Spark Energy Meter does not measure the ionisation energy but it measures the spark burn time energy which is the substantially larger of the two values.

The diagram of Fig.1 shows the capacitances and the discharge current pathways at the moment the spark strikes for a real spark plug in the initial or ionisation phase. The ignition coil's self capacitance, the wiring capacitance and the spark plug's capacitance all contribute to these high initial peak currents.

Clearly if a resistor spark plug (about 5kΩ) is used, these high initial and brief peak currents are significantly reduced to a value of 10kV/5kΩ or about 2A. This is why resistor spark plugs suppress radio interference. The same applies to resistive ignition cable which reduces RFI from the ignition system. Inductive ignition cable also reduces the peak currents.

As shown in Fig.1 though, all cable has some components of resistance $R_W$, inductance $L_W$ and distributed capacitance. There was a method tried many years ago to increase these initial spark ionisation currents by adding capacitance at the spark plug. While this probably had some small benefits the idea never took off. Probably because it is the spark burn time energy that is largely responsible for initiating combustion, not the initial spark ionisation energy.

When using a zener diode as a dummy spark plug a series 5kΩ resistor is also helpful in providing a ballast for the zener to reduce initial peak currents from the capacitances of the ignition coil secondary and wiring. A convenient feed through or coupling device into a spark energy meter is therefore a typical resistor style spark plug.

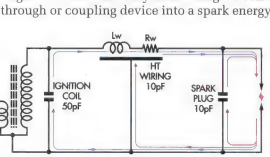



**Fig.1: the capacitances and the discharge current pathways at the moment the spark strikes for a real spark plug immediately after the initial or ionisation phase.**

For a spark energy meter, the spark burn time energy is calculated from the product of the spark plug's (or zener diode's) voltage drop and electrical charge in Coulombs which has passed by that voltage drop over the duration of the spark. This is because work (in Joules) is equal to the product of the charge (in Coulombs) and the voltage field (in Volts) which the charge has traversed.

Since the spark current may have a variety of amplitude versus time profiles, the current needs to be integrated over the course of the spark time to yield the transferred charge.

## CDI versus MDI spark current characteristics

The basis of a Magnetic Discharge Ignition or MDI system (Kettering) whether it is electronically assisted or not, is the storage of energy in the magnetic field of the ignition coil, then the release of this energy to generate the spark.

In MDI systems the spark always extinguishes before all of the stored magnetic field energy has been dissipated. The residual magnetic field energy that remains after the spark burn time is dissipated later as decaying oscillations visible on the primary or secondary of the ignition coil in an oscilloscope recording.

The same applies to CDI. In most cases after the spark burn time, there is still some residual energy in the discharge capacitor or in the ignition coil's field (which has acquired that energy from the capacitor in a series of oscillations during the spark burn time).

## Energy transfer efficiency

Measurements with a spark energy meter for an MDI system show that the spark burn time energy is typically about 60% of the total magnetic stored energy prior to the spark. The value for CDI is much lower. About 16% of the energy stored in the discharge capacitor's electric field becomes spark energy for a CDI system using a standard oil filled Kettering style coil. However there are other mitigating

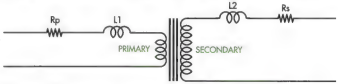



**Fig.2(a): the transformer's actual leakage inductance and resistance (winding capacitance not shown).**

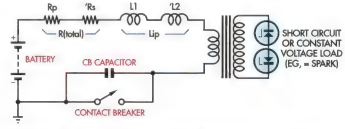



**Fig.2(b): leakage inductance and resistance transposed to primary circuit.**

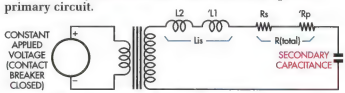
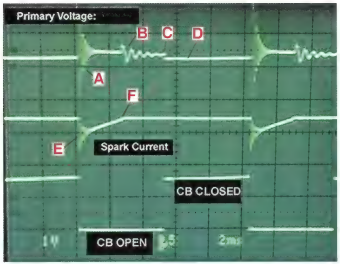



**Fig.2(c): leakage inductance and resistance transposed to secondary circuit.**




**Scope 1: this photo shows the relationship between the primary voltage on a standard Kettering ignition coil (top trace) and spark current when the points open and close.**

factors because the peak spark currents are higher in CDI than MDI and with a good transformer ignition coil for CDI the energy transfer efficiency can reach 25%.

The energy losses in MDI primarily relate to the resistances of the ignition coil windings and also the spark ionisation energy is not factored into a spark burn time energy measurement and there is some residual magnetic field energy left behind at the end of the spark burn time in the coil's magnetic field.

There are also other losses related to the magnetic and dielectric properties of the ignition coil.

The spark as an electrical load and viewed from an alternating current perspective acts much like a short circuit on the ignition coil secondary because the spark voltage drop is low compared with what would be the ignition coil's open circuit secondary voltage (as already noted).

Fig.2(a) shows a model transformer. There is leakage reactance, winding resistances and distributed winding capacitances. Fig.2(b) shows the heavy loading on the secondary winding by the spark during the spark burn time and this has some interesting effects, shown in Fig.2(c).

The primary circuit can be regarded as containing the total leakage inductance $L_{1P}$. This represents a series inductance due to the fact that the primary & secondary turns are not perfectly magnetically coupled. There is also the primary winding resistance $R_p$ and a resistance reflected into the primary winding '$R_s$, which is the secondary winding resistance transformed into the primary by the square of the turns ratio.

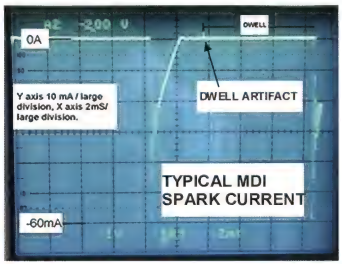
Therefore as the magnetic field of the core collapses, Lip resonates with the points capacitor (CB Capacitor) and R(total) damps the oscillations so decaying oscillations are seen in the spark current. These oscillations are typically around 8kHz and are seen in the scope screen photo, Scope1. The top trace is the primary voltage on a standard Kettering ignition coil. Even with no contact breaker capacitor fitted oscillations still occur at a higher frequency because of the self capacitance of the primary winding.

Although the negative-going spark current (second trace) is oscillatory in the early phase of the spark, the oscillations damp out prior to the end of the spark burn time and are never large enough to make the spark current swing to a positive value in the MDI system.

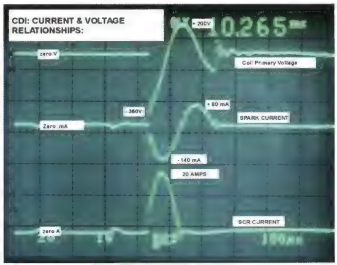
When the spark current extinguishes at F not all the stored magnetic energy of the core was dissipated, so then the coil primary inductance resonates with the contact breaker capacitor (contact breaker is still open) at around 2kHz. The coil's secondary with its self-inductance and distributed capacitance also resonate at a similar frequency. This is seen in the recording of primary voltage between B & C. This 2kHz oscillation is abruptly terminated when the contact breaker closes at C, however it has almost decayed away by then anyway.

With 12V applied to the ignition coil primary (the points close or the switching transistor or Mosfet conducts) this effectively shorts out the primary from the alternating current perspective and again the current builds and the magnetic field climbs in the ignition coil's core. A constant 12V is applied across the primary at as shown in Fig.2(c) and in Scope1 at D.

Note that after the points close, the peak secondary voltage is the 12V supply times the coil's turns ratio. So a




**Scope 2: a typical MDI spark current profile in more detail with the negative going current and the oscillations in the early phase of the spark current.**




**Scope 3: the timing of the coil voltage and spark current and SCR current for a typical CDI. Note the spark current is bidirectional.**

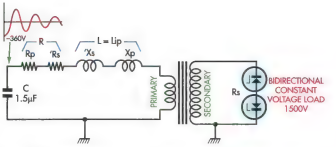



**Fig.3: CDI system capacitor discharging into coil primary.**

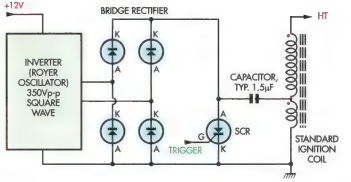



**Fig.4: functional diagram of a capacitor discharge ignition.**

positive voltage appears on the secondary terminals that can be as high as 1200V with a 1:100 ratio coil. While this is not enough voltage to initiate a spark with a real spark plug it can result in a small current transient when a 1000V bidirectional zener diode is being used as a "dummy spark plug" measuring an ignition coil's output directly and not via the spark gap in a distributor.

This false spark current can be called a "Dwell Artefact" and can be seen in spark current recordings with 1000V bidirectional zener dummy spark plugs directly connected to an ignition coil output. Also a zener dummy spark plug has to be bidirectional or it would conduct like a normal diode in reverse when the contact breaker closed and effectively short out the coil secondary at that time when the current was building up in the primary.

One might also expect that after the points close, there should be some oscillations visible on the secondary winding caused by the leakage reactance now appearing in the secondary circuit and oscillating with the coil's secondary self capacitance as shown in Fig.2(c). These are easy to record with an oscilloscope loosely coupled to the insulation of the high voltage cable and they have a frequency around 7.5kHz with a typical ignition coil.

Scope2 shows a typical MDI spark current profile in more detail with the negative going current and the oscillations in the early phase of the spark current. The small positive going spike or "Dwell Artefact" is seen at the start of the dwell time (points closed) because this scope photo was taken using a 1000V bidirectional dummy zener spark plug.

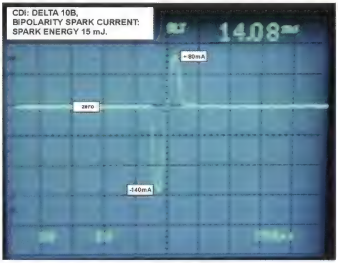
Ignoring the spark current oscillations that peak at -60mA, the waveform is roughly triangular with a starting point roughly around -30mA and decaying to zero over about two milliseconds.

A similar situation applies with the spark loading the ignition coil in a CDI system, in that the ignition coil's leakage reactance resonates with the discharge capacitor value during the spark time. However in the CDI case the ignition coil is acting as a pulse transformer rather than an energy storage device and the stored energy was in the electric field of the discharge capacitor rather than in the magnetic field of the coil.

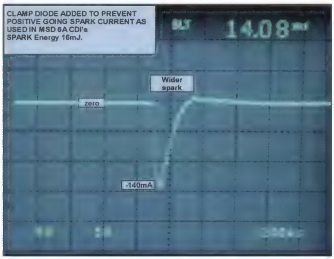
Transformer style ignition coils are much more efficient for use with a CDI units than using the conventional oil-filled Kettering style coil. In MDI the energy storage and energy release occur at separate times, so the coil properties such as the leakage reactance between the primary and secondary are less important than for CDI, where ideally the ignition coil behaves as an ideal transformer. Fig.3 shows the electrical arrangement when a CDI is transferring the stored energy from the discharge capacitor into the spark.

The general format for a CDI unit is shown in Fig.4 but there are many variations using SCRs or Mosfets (as in the latest SILICON CHIP design in the December 2014 issue).

The capacitor's initial voltage is typically in the order of 360V to 400V and its charge is dumped into the primary winding of the ignition coil by the SCR which is triggered by the contact breaker or electronic sensor in the distributor. In CDI the spark current oscillations during the spark time




**Scope 4: the spark current profile from a Delta 10B CDI unit which uses an SCR. The spark current in CDI is bidirectional.**




**Scope5: when a primary winding clamp diode is added to the circuit, the positive-going component of the spark current flips around to become a negative-going spark.**

**Scope photos in this feature are based on the venerable Mark10B Capacitor Discharge Ignition from Delta Products. As they say, "an oldie but a goodie!"**

are the result of the discharge capacitor, typically about 1µF to 2µF in value, resonating with the leakage inductance $L_{ip}$ of the ignition coil.

The timing of the coil voltage and spark current and SCR current for a typical CDI are shown in the scope photo of Scope3.

The measured spark current is the ignition coil's secondary current. The discharge capacitor has lost its energy (has zero volts) at about the time the spark current first peaks to its negative value of -140mA. The discharge capacitor then charges in reverse to +200V. The energy required to do this has not come from the DC:DC converter directly in the CDI unit but has come from magnetic energy imparted to the core of the ignition coil by the discharging capacitor.

The capacitor again discharges this time from +200V (with the currents in the reverse direction) to generate the positive peak of spark current to +80mA. The circuit which allows the positive going spark current does not involve the SCR at that time which is switched off and a little reverse biased. The reverse primary current (and positive polarity spark current) flows in a circuit completed by the bridge rectifier diodes on the output of the DC:DC converter which become forward biased.

Therefore although CDI is called "capacitive discharge ignition" it is a combination of energy exchange in a resonant circuit between the electric field of the capacitor and the magnetic field of the coil. Even if one just considers the initial negative-going peak of spark current, half of that was formed by magnetic energy of the ignition coil returning to the electric field of the capacitor.

CDI might have been better called "Capacitive Oscillatory Ignition" or COI. So really it is not true CDI as it requires the magnetic component and voltage step up function from the ignition coil to operate. This is the case when standard ignition coils are used and the capacitor is initially charged to only around 400V prior to discharge.

True CDI does exist in aviation exciter systems when a capacitor charged to a very high voltage, discharges after a separate spark ionisation process, directly into the spark plug. Typically this produces a high initial peak current and an exponential decay. In this instance there is no energy exchange with magnetic field energy.

Scope4 shows the spark current profile from a Delta 10B CDI unit which uses an SCR. Note that unlike an MDI system which has a unidirectional negative-going spark current, the spark current in CDI is bidirectional.

Some brands of CDI are modified with an additional energy recovery or clamp diode on the ignition coil primary to only generate a negative-going spark current, for example the MSD 6A unit.

The CDI spark burn time has a much shorter duration than MDI at about 200µs versus 1ms or more for the MDI system. However the peak currents are much higher at around -140mA for the first negative peak.

Some CDIs can produce another half cycle of oscillation of spark current if the SCR gate is held on for a longer period than a full cycle of current. Yet others can put a sequence of sparks thought to improve the probability of combustion.

When the primary winding clamp diode is added to the circuit as in the MSD 6A CDI unit, the positive-going component of the spark current flips around to become a negative-going spark current (See Scope5) but this has little effect on the total spark energy.

## Estimating spark energy from scope recordings

Typical spark energies in MDI ignition systems are in the order of 20 to 60mJ per spark and have durations of around 0.5 to 2ms; 1ms being common.

Assuming the ignition coil is wired correctly, the polarity of the spark current is negative-going and has a roughly right-angle triangle profile. Ignoring the initial oscillations of spark current, the peak currents are typically about -30mA, decaying nearly linearly to zero over the spark burn time.

The exact energy depends on the dwell time and how much energy is stored in the coil prior to the spark. So for this example a -30mA peak spark current, has an average current of about 15mA over a 2ms interval. The charge transferred across a 1000V load (the spark) is about 30mQ (millicoulombs) resulting in about 30mJ (millijoules) per spark.

CDI system spark energies are typically lower than MDI; usually less than half, however the peak spark currents are higher than MDI and the spark duration is usually much shorter. Also CDI spark currents are roughly sinusoidal in shape. So in Scope4 for the Delta 10B unit above, the negative peak spark current is nearly sinusoidal.

It peaks at -140mA and has a duration of about 100µs, the charge in Coulombs transferred is the average current x time which is roughly 0.64 x 0.14 x 100µs = 8.96µC, and multiplying that by the spark voltage (1000V) yields 8.96mJ. Likewise for the positive-going spark current, the energy is 0.08A x 0.64 x 100µs x 1000 = 5.12mJ, the total energy being 5.12 + 8.96 = 14mJ.

The Spark Energy Meter described elsewhere in this issue (with a proper current-time integrator) reported 15mJ for that particular example.

Although CDI overall spark energies are lower than MDI, they are delivered over a shorter time frame than MDI sparks and they have higher peak currents and peak power. Therefore they have a higher temperature than MDI sparks. For example the CDI spark cited above has an SPP value of 15mJ/200µs = 75W and the MDI spark cited above has an SPP of 30mJ/2ms = 15W.

While it is easy to estimate spark energy from an oscilloscope recording of the spark current profile and the knowledge of the spark sustaining voltage it is much more convenient to use the Spark Energy Meter which can measure the energy immediately. SC

Now see the build-it-yourself Spark Energy Meter, commencing on page 57

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*See website for full specifications.*

- Real Time Sample Rate: 40MSa/s
- Input Range: 1mV to 40V per division
- 114(H) x 74(W) x 29(D)mm

### EtherMega Arduino Compatible Board XC-4256

The ultimate network-connected Arduino-compatible board combining ATmega2560 MCU, onboard Ethernet, a USB-serial converter, a microSD card slot, Power-Over-Ethernet support (use XC-4254, sold separately), and an onboard switchmode voltage regulator.

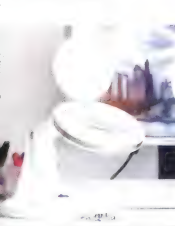
- 10/100base-T Ethernet
- 54 digital I/O lines
- 16 analogue inputs

**ALSO AVAILABLE:**

**4 CHANNEL POE MIDSPAN INJECTOR FOR ARDUINO**
XC-4254 **$26.95**

**MEGA PROTOTYPING SHIELD FOR ARDUINO** XC-4257 **$17.95**

$119



$49.95

### Desktop LED Magnifying Lamp QM-3544

**Possibly the most useful device you could have in your workshop! Magnify and inspect your projects under the ultra bright LED illumination and precision lens for that clear and strain-free viewing. Being LED, there's no delay in start-up and they'll never need replacing.**

**+ 3x and 12x magnifying**
**+ Low power consumption & heat**
**+ 320(H) x 95(Dia)mm**

$99
QM-3548

DESK-MOUNT VERSION ALSO AVAILABLE:

### 5 DIOPTRE LED ILLUMINATED MAGNIFYING LAMP QM-3548

**WE ARE MOVING: JAYCAR LIVERPOOL**

**CNR OF SAPPHO ROAD & HUME HIGHWAY**
**WARWICK FARM NSW 2170 PH: (02) 9821 3100**



**To order phone 1800 022 888 or visit www.jaycar.com.au**

**DOUBLE POINTS FOR REWARDS CARD HOLDERS ON OUR RANGE OF DIGITAL MULITMETERS***

*Valid for purchase of QM-1549, QM-1571, QM-1543, QM-1576, QM-1548, QM-1444, XC-5078, QM-1594 or QM-1493.

## IP67 Rated True RMS Digital Multimeters

Our range of high quality true RMS digital multimeter (DMM) provides the durability, accuracy and performance needed for the professional user. All DMMs are packed with multi functions to suit a wide range of electrical work, including AC Voltage, DC Voltage, AC Current, DC Current, Resistance, Capacitance, Frequency, Temperature (except QM-1549), Continuity and Diode Test.

- CAT IV 600V
- Auto-ranging, data hold, relative measurement

| | QM-1549 | QM-1571 | QM-1543 | QM-1576 |
|---|---|---|---|---|
| Special Features | Value-for-money CAT IV DMM for most electrical works | Wireless USB interface and logging software for computer based analysis | Drop proof to 2m. Includes bargraph and K-type thermocouple. | View live data, diagnose, email & share your results to the Cloud - all from your Smartphone! |
| Display (Count) | 4,000 | 4,000 | 40,000 | 40,000 |
| Security Category | Cat IV 600V | | | |
| Volts DC/AC | 1,000V | | | |
| Amp DC/AC | 10A | | | |
| Resistance | 40M | | | |
| Capacitance | 100µF | 200µF | 40mF | 40mF |
| Frequency | 10MHz | | | |

DOUBLE POINTS

$79.95 QM-1549 | $109 QM-1571 | $149 QM-1543 | $219 QM-1576

## CAT III MULTI-FUNCTIONAL DIGITAL MULTIMETERS

Suitable for electrical, automotive, network, field service or bench repairs

DOUBLE POINTS

$49.95

### Inductance/ Capacitance Meter

QM-1548

Ideal for audio enthusiasts designing their own crossovers.

- 600V, 2000 count
- AC/DC voltages up to 1000V/750V
- AC/DC current up to 10A
- Hfe transistor & diode test

DOUBLE POINTS

$59.95

### Automotive Meter

QM-1444

Features an inductive pickup for RPM measurement, dwell angle, and works with engines of 2 to 10 cylinders.

- 600V, 4000 count
- AC/DC voltages up to 600V
- AC/DC current up to 10A
- RPM x1, x10

DOUBLE POINTS

$79.95

### Network Cable Meter

XC-5078

Ideal for network installers or technicians, easily check cable integrity or measure AC & DC voltage, etc without needing to carry two separate devices.

- 600V, 2000 count
- AC/DC voltages up to 600V
- AC/DC current up to 200mA
- Resistance measurement

DOUBLE POINTS

$99

### Environment Meter

QM-1594

Combines the functions of a sound level meter, light meter, humidity meter and temperature meter to help get the job done faster.

- 600V, 4000 count
- AC/DC voltages up to 250V
- AC/DC current up to 10A
- Resistance, non-contact voltage measurement

DOUBLE POINTS

$199

### Insulation Meter

QM-1493

Suitable for high voltage insulation testing in electrical and electronic testing applications.

- 1000V, 4000 count
- Test Voltage & Current: 125V, 250V, 500V, 1000V @1mA nominal
- Insulation resistance up to 4000M Ohm
- Bargraph, test hold & lock

FROM $39.95

### Protect Your DMM

Ideal for sensitive instruments and test equipment, these tough aluminium attache cases are supplied with removable 15mm square foam pieces and a foam insert on the lid for complete protection.

- Lockable, 2 keys included

**SMALL** HB-6355 **$39.95**
407(W) x 277(D) x 95(H)mm

**LARGE** HB-6356 **$69.95**
450(W) x 320(D) x 145(H)mm

**ALL THE DMMS ADVERTISED INCLUDE QUALITY TEST LEADS.** *See website for full specifications.*

### Fuses for CAT IV DMM

Fast acting ferrule fuses designed for use in circuits with high AC fault current capacity. Three models to suit our IP67 CAT IV rated DMMs.

**500MA 1000V** SF-2278 **$9.95**
**800MA 1000V** SF-2279 **$9.95**
**1.0A 1000V** SF-2277 **$14.95**

### LOOKING FOR ABS CASES?

Jaycar also stocks high quality ABS cases with purge valves to suit maintenance, service, research and development applications.

*See website for more details.*

FROM $9.95

## GREAT VALUE ACCESSORIES FOR YOUR MULTIMETERS

### Meter Probe Alligator Clips

WT-5220

$3.95

Turn your DMM probes into clips!

- Approx 55mm long
- Jaw opening 8mm
- Sold as a pair
  1 red, 1 black

### Multimeter Carry Case HB-6361

Hard wearing case perfect for protecting your valuable multimeter from harsh conditions.

- 190(L) x 125(W) x 45(D)mm

$6.95

### Pro Cat IV Multimeter Probes

WT-5338

$17.95

Suitable for 4mm banana sockets. Probe safety cover with slot for delicate work.

- Sold as a pair

REWARDS CARD OFFER
BUY ALL 3 FOR $19.95*
SAVE $8.90

*Valid for purchase of WT-5220, HB-6361 & WT-5338


Jaycar TRADE CARD

ATTENTION ALL TRADIES!

IF YOU'RE A PROFESSIONAL AND REGULARLY PURCHASE ELECTRONICS GOODS FOR BUSINESS PURPOSES, YOU MAY BE ELIGIBLE FOR SPECIAL TRADE PRICES AT JAYCAR COMPANY STORES* ON SELECTED ITEMS.

SPEAK WITH OUR FRIENDLY STAFF AT YOUR LOCAL JAYCAR STORE TODAY & FIND OUT HOW.

*Conditions apply. See website for T&Cs

## CAT III CLAMP METERS

Our range of CAT III Clamp Meters makes the best general troubleshooting tool for commercial and residential electricians and includes features found on more expensive units such as autoranging, data hold, non-contact voltage, relative measurement and auto power-off. Multi function with Resistance, Capacitance, Frequency and Temperature, all Clamp Meters are supplied with quality temperature probe and carry case.

### 400A AC Clamp Meter
QM-1561
- Cat III 600V, 4000 count
- AC/DC voltages < 600V
- AC current < 400A
- Jaw opening 30mm

### 400A AC/DC Clamp Meter
QM-1563
- Cat III 600V, 4000 count
- AC/DC voltages < 600V
- AC/DC current < 400A
- Jaw opening 30mm

### 1000A True RMS AC/DC Clamp Meter
QM-1566
- Cat III 600V, 4000 count
- AC/DC voltages < 600V
- AC/DC current < 1000A
- True RMS, min-max, bargraph and more
- Jaw opening 40mm

$59.95 QM-1561 | $119 QM-1563 | $139 QM-1566

### CAT III Non-Contact AC Voltage Detector
QP-2268 **$19.95**

A must have for every toolbox. Detects AC voltages from 50 to 1000V. The unit will glow green when safe, and flash red and beep when voltage is detected.
- LED flashlight function
- 2 x AAA batteries included
- 159(L) x 23(D)mm

REWARDS CARD OFFER $9.95* SAVE $10

*Valid with purchase of QM-1561, QM-1563 or QM-1566.

**TECH TIP!**
Troubleshooting electrical problems in non-linear loads can be difficult and result in wrong readings if you do not have the right tool. Our range of True RMS test equipment is designed specifically for applications where accurate readings are essential. Don't put your job (or reputation) at risk, find out how we can help you in-store now.

## ENVIRONMENTAL TEST & MEASUREMENT EQUIPMENT

FREE K-TYPE PROBE FOR REWARDS CARD HOLDERS* QM-1282

QM-1282 VALUED AT $14.95.

### 2-Input Thermocouple Thermometer QM-1601 $79.95
Fast response and laboratory accuracy, works with K-type thermocouples and offers 0.1 or 1° user-selectable resolution over the entire measurement range. Holster and thermocouples included.
- 2000 count
- Range: -50 to 1300°C (±0.5%)
- Celsius & Fahrenheit measurements
- Backlit LCD, max and hold functions

### Temperature/Humidity USB Dataloggers FROM $99
Log temperature and humidity readings and store them in internal memory for later download to a PC.
- Windows 2000/XP/Vista compatible
- Temp range: -40 to 70°C (±1°C)
- Humidity range: 0 to 100% (±3°C)
- 32,000+ memory samples

**DIRECT PLUG-IN TYPE** QP-6013 **$99**

**USB/LCD MODEL** QP-6014 **$149** (Shown)

### Non-Contact Thermometer $99
QM-7221
With a wide temperature range and dual laser targeting, this portable instrument is easy to use for quick and accurate temperature checking of any surface.
- 12:1 distance-to-spot ratio
- Temperature range: -50°C to +650°C (±1%)

**ALSO AVAILABLE:**

**PROFESSIONAL HIGH TEMPERATURE 30:1 NON-CONTACT THERMOMETER** QM-7226 **$189**

### Automotive Multi-Function Circuit Tester QM-1494 $49.95
Designed for 12/24v vehicles. It also tests polarity, voltage, short/open status, lights and more.

FREE OBD2 PLUG-IN MEMORY SAVER FOR REWARDS CARD HOLDERS* PP-2140

PP-2140 VALUED AT $5.95.

### Digital Light Meter $49.95
QM-1587
A handy meter for lab work, architectural, engineering and construction. 4 ranges from 0.01 to 50,000 Lux.
- Auto zeroing, data hold
- Separate Photo Detector
- 188(L) x 64(W) x 24.5(D)mm

### Digital Sound Level Meter $99
QM-1589
This unit can measure both A and C weightings and diagnose 'ambient' reading or short noise. Features data hold and min/max functions.
- 30 to 130dB

**ALSO AVAILABLE:**

**PROFESSIONAL SOUND LEVEL METER WITH CALIBRATOR** QM-1592 **$399**

### Professional Laser Distance Meter $129
QM-1622
This highly accurate unit measures the distance between two points beyond the common tape measure. It also automatically calculates area, volume or height.
- Measurement range: 0.05 to 35m (±1.5mm)
- Stores up to 20 measurements

REWARDS CARD OFFER 10% OFF!

FROM $499

### Digital Storage Oscilloscopes
The advantages of a DSO gives you capabilities that simply aren't possible with any analogue oscilloscope, including trace capture, PC interface, storage of data on portable media etc.
- Sampling rate: 500MSa/s (QC-1932) / 1GSa/s (QC-1934)
- Memory depth: 32k (QC-1932) / 2M (QC-1934)

**25MHZ DUAL CHANNEL WITH 5.7" SCREEN** QC-1932 **$499**

**100MHZ DUAL CHANNEL WITH 7" SCREEN** QC-1934 **$899**

EARN A POINT FOR EVERY DOLLAR SPENT AT ANY JAYCAR COMPANY STORE* & BE REWARDED WITH A $25 REWARDS CASH CARD ONCE YOU REACH 500 POINTS! *Conditions apply. See website for T&Cs

REGISTER ONLINE TODAY BY VISITING:
www.jaycar.com.au/rewards

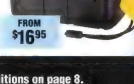
### Protect Your Instruments
Black waterproof ABS cases for storing or transporting test equipment, delicate electronic devices, radios and more.
- IPX8 waterproof and shockproof
- Lanyard included

**SMALL** 182(L) x 120(W) x 42(H)mm HB-6421 **$16.95**

**MEDIUM** 182(L) x 120(W) x 75(H)mm HB-6423 **$19.95**

**LARGE** 655(L) x 482(W) X 495(H)mm HB-6425 **$29.95**

REWARDS CARD OFFER 10% OFF!



FROM $16.95

## CORE ESSENTIALS

FROM $7.75

### Round Cable Suppression Sleeves

Add extra noise suppression to mains cable with this simple hinged ferrite core. Snap-on design for quick installation.

*See website for more details.*

**SINGLE** Suits up to 12.5mm Dia. LF-1290 **$7.75**

**2 PACK** Suits up to 7.0mm Dia. LF-1294 **$7.95**

**4 PACK** Suits up to 8.2mm Dia. LF-1292 **$9.95**

$36.95

### 12VDC Mechanical Axial Fan

YX-2517

High quality ventilation fans suitable for field service replacements. Long lasting 60,000 hours at 25°C and wide operating temperature range -20°C to +70°C.

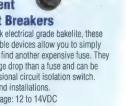
- 120mm Ball Bearing

**ALSO AVAILABLE:**

**120MM FAN FINGER GUARD** YX-2515 **$4.95**

**1.2M FAN POWER LEAD** PS-4160 **$3.95**

*Wide range of 12VDC/240VAC axial fans from 30mm to 150mm also available. See website for more details.*



$26.95 ea

### High Current DC Circuit Breakers

Moulded in black electrical grade bakelite, these rugged and reliable devices allow you to simply reset rather than find another expensive fuse. They offer lower voltage drop than a fuse and can be used as an occasional circuit isolation switch. Ideal for car sound installations.

- Operating voltage: 12 to 14VDC

**70A 0.120Ω** SF-2265 **$26.95**

**100A 0.075Ω** SF-2266 **$26.95**

*Wide range of AC & DC circuit breakers also available. See website for more details.*

**FREE PCB WASH FLUX REMOVER 1L FOR REWARDS CARD HOLDERS*** NA-1070

NA-1070 VALUED AT $12.95

NEW

$12.95

### PCB Wash Flux Remover

NA-1070

Chemtools PCB Wash flux remover is a water-based solution of biodegradable solvents and detergents suitable for use in ultrasonic tanks for various applications including: metal parts degreasing, flux removal and cleaning of sensitive electronic parts.

- 1L bottle

$149

### 2.5L 170W Digital Ultrasonic Cleaner YH-5412

Professional quality machine for quick and convenient cleaning of industrial parts, electronic equipment and more. Features a 2.5L 304-grade stainless steel bowl and controllable heating element.

- 5 selectable time settings
- 290(W) x 223(D) x 185(H)mm

$249

### Inspection Camera

**WITH 3.5" DETACHABLE WIRELESS LCD**

QC-8712

View and record video and pictures in confined and dark locations. The head and flexible boom are IP67-rated for use in harsh environments.

- 1m flexible boom
- 2.4GHz wireless transmission
- Hook, mirror, magnet and 2GB microSD card included

**ALSO AVAILABLE:**

**EXTENSION SHAFT 2M** QC-8702 **$79**

## DOUBLE POINTS FOR REWARDS CARD HOLDERS ON THESE HAND TOOLS*

*See Page 8 for Double Points details*

DOUBLE POINTS

FROM $16.95

### High Quality Tough Pliers/Cutters

These drop forged alloy steel units are manufactured to the highest standard for electrical safety and mechanical strength. All units include 1000VAC rated handles and are GS approved.

**6.5" LONG NOSE PLIERS** TH-1986 **$16.95**

**7" COMBINATION PLIERS** TH-1984 **$19.95**

**6" SIDE CUTTERS** TH-1985 **$17.95**

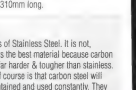
DOUBLE POINTS

$22.95

### Cat5 Adjustable Punch-Down Tool

TH-1740

Designed for seating wire into terminal blocks. Adjustable internal impact mechanism. Supplied with 88 blade. 152mm long.



DOUBLE POINTS

$24.95

### Copper Cable Shears

TH-1900

Features a precision cutting head forged from carbon steel attached to drop forged steel handles for extra leverage. Cuts copper cable up to 35mm² and any cable up to 2GA, 310mm long.

DOUBLE POINTS

$24.95

### 1000V 7-Piece Screwdriver Set

TD-2022

High Quality, bright red drivers that are insulated right to the tip. Storage case included. DIN EN 60900.

*See website for full contents.*

DOUBLE POINTS

$29.95

### 30-Piece Electronic Tool Kit

TD-2107

An excellent tool kit for electronic or computer repairs with all the essentials - cutters, pliers, screwdrivers (Phillips head, slotted, Posidrive), nut drivers etc.

*See website for full contents.*

**TECH TIP!**

We are big fans of Stainless Steel. It is not, however, always the best material because carbon steel is in fact far harder & tougher than stainless. The problem of course is that carbon steel will rust if not maintained and used constantly. They will, however, pay you back every day because they will stand up to heavy wear & tear.

DOUBLE POINTS

$49.95

REWARDS CARD OFFER

ADD 3 DIES FOR $40*

SAVE $13.85

*Valid with purchase of TH-2000*

### Heavy Duty Crimp Tool

**WITH QUICK CHANGE DIES**

TH-2000

Heavy duty and ergonomic crimper that uses quick interchangeable dies, no screwdriver needed. Ratchet mechanism for maximum power and quick release.

**QUICK CHANGE DIES**

**AVAILABLE SEPARATELY:**

**6P6C RJ11/12** TH-2001 **$17.95**

**8P8C RJ45** TH-2002 **$17.95**

**INSULATED TERMINALS** TH-2003 **$17.95**

**BNC/TNC RG58/59/62** TH-2004 **$17.95**

**F CONNECTORS CATV RG6/59** TH-2005 **$17.95**

**NON-INSULATED TERMINALS 26-18AWG** TH-2006 **$17.95**

**NON-INSULATED TERMINALS 20-10AWG** TH-2007 **$17.95**

**SMA/FIBRE OPTIC 1.09-6.48MM** TH-2008 **$17.95**

**SMA/FIBRE OPTIC 1.07-4.52MM** TH-2009 **$17.95**

## FREE LEATHER UTILITY BELT FOR REWARDS CARD HOLDERS* HB-6371

*Valid with purchase of both HB-6301 and HB-6302*

$19.95

### Pro Leather Tool Utility Belt

HB-6373

Strap this to your waist to keep your most used tools on you at all times. Features a number of pockets and 2 leather loops suitable for carrying a hammer, measuring tape and more.

*Tools not included*

- Adjustable belt size

$29.95

### Portable Storage Cabinet

HB-6301

Perfect storage solution for fasteners and other small parts. Unique "double lock" design on each storage box keeps contents in their bins when shut. Commercial grade.

- 12 storage compartments
- 300(W) x 310(H) x 145(D)mm

$59.95

### Aluminium Attache Case HB-6352

High quality case, supplied with removable tool pallet. The lid includes a document holder and the padded case includes 5 dividers that can be rearranged/ removed. Lockable, supplied with 2 keys.

- 455(W) x 330(H) x 152(D)mm

$149

REWARDS CARD OFFER
ADD 4 TIPS FOR $30[1]
SAVE $21.80

[1] Valid with purchase of TS-1390

$299

REWARDS CARD OFFER
ADD 4 TIPS FOR $40[2]
SAVE UP TO $39.80

[2] Valid with purchase of TS-1574

## 60W Lead-Free Soldering Station WITH LCD PANEL TS-1390

This excellent soldering station is particularly suited to lead-free soldering and is just as capable with ordinary leaded solder. The soldering pencil is fitted with a soft insulated rubber grip and has a silicon rubber sheathed power cable.

- Microprocessor controlled
- Temperature range 160°C to 480°C
- Set and actual temperature display
- 130(L) x 170(W) x 240(H)mm

**SPARE TIPS AVAILABLE:**

**0.4MM CONICAL TIP** TS-1391 **$12.95**
**1.0MM CONICAL TIP** TS-1392 **$12.95**
**2.0MM CHISEL TIP** TS-1393 **$12.95**
**3.0MM BEVEL TIP** TS-1394 **$12.95**

## 60W ESD Safe Lead-Free Solder/Rework Station TS-1574

Complete solder/desolder station for production and service use. Features precise temperature control in 1° increments via the simple up/down buttons. Soldering/rework functions can be operated independently of each other.

- Microprocessor controlled
- Temperature range: 160°C to 480°C
- Celsius and Fahrenheit display
- 225(L) x 215(W) x155(H)mm

**SPARE TIPS AVAILABLE:**

**2.5MM SINGLE TIP** TS-1575 **$13.95**
**4.4MM SINGLE TIP** TS-1576 **$13.95**
**10X10MM QUAD TIP** TS-1577 **$19.95**
**15X15MM QUAD TIP** TS-1578 **$19.95**

# FOR YOUR WORKSTATION

## Workbench Clamp Vice TH-1769

The base will clamp to any bench or table up to 55mm thick and the 40mm jaws will take a job up to 58mm in size. Once in position, the head is easily fixed in position with a quick release lever.

- 270° rotatable jaws
- 115(W) x 94(D)mm

**ALSO AVAILABLE:**
**360° BENCHTOP VICE** TH-1766 **$29.95**

$19.95

## 150mm Precision Digital Vernier Calipers TD-2082

Features a 5 digit LCD display that will show readings in metric and imperial. The caliper can be zeroed at any point along the scale making comparative measurements easy. Battery included.

- Thumbscrew slide damper
- Resolution: 0.01mm/0.0005"

$29.95

$29.95

## LED Headband Magnifier QM-3511

This magnifying headset leaves both hands free and can be worn over prescription or safety glasses.

- Adjustable head strap
- Built-in LED work light
- 1.5X, 3X, 8.5X or 10X magnification
- Requires 2 x AAA batteries

## Lead-Free Solders

99.3% tin, 0.7% copper lead-free. Two sizes to suit every application.

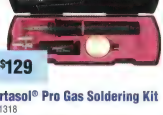
**200G ROLL**
**0.71MM** NS-3088 **$17.95**
**1.00MM** NS-3094 **$17.95**

**500G ROLL**
**0.71MM** NS-3090 **$42**
**1.00MM** NS-3096 **$42**

FROM $17.95

PCB not included.

$19.95



$129

## Portasol® Pro Gas Soldering Kit TS-1318

This kit contains a Portasol Pro Piezo gas soldering iron, cleaning sponge and tray, and various useful tips.

- Cordless butane gas powered
- Click-to-ignite function
- 15-75W adjustable power

**ALSO AVAILABLE:**
**SUPER PRO KIT** TS-1328 **$159**
**BUTANE GAS** NA-1020 **$5.95**

$149

## Digital Bench Scale QM-7264

Precision 1kg electronic scale with 0.01g resolution. Weighs in grams, ounces, pounds, grains, carats and troy ounces.

- Automatic calibration
- Tare and counting function
- Powered by mains or batteries (not included)
- 175(W) x 75(H) x 260(D)mm

FROM $149

MP-3802

## Compact Switchmode Power Supply

Compact size, high current, variable output and fan cooling. Protected against thermal overload and short circuit and will display a warning LED in the event of a fault condition.

**0-24VDC 18A** MP-3800 **$149**
**0-16VDC 35A** MP-3802 **$199**

## PCB Holder TH-1980

Essential for every technician's workbench, this PCB holder with movable arm can hold PCB up to 200(L) x 140(W)mm in size. *PCB not included*

- 360° rotatable at 15° increments
- Heavy base, total weight: 450g
- 300(L) x 165(W) x 125(H)mm

$29.95

## 10x LED Magnifier WITH SCALE QM-3539

Superbly built handheld all-metal magnifier with 3 LED illuminating lights. Provides 10 dioptre magnification with built-in scale so you can take measurements of an object.

- Built-in metric and imperial scale
- Uses 2 x AA batteries (included)
- 26mm eyepiece, 180mm long

# 2:1 HEATSHRINK TUBING

High quality and VW-1 flame retardant heatshrink tubes. Shrink easily with a heatgun, hairdryer or gas burner.

- Black colour
- Available in 7 sizes
- Sold in 5m handy pack

**ALSO AVAILABLE IN RED COLOUR.**
*See website for details.*

**1.5MM DIAMETER** WH-5680 **$5.45**
**2.5MM DIAMETER** WH-5681 **$6.45**
**3.0MM DIAMETER** WH-5682 **$6.95**
**5.0MM DIAMETER** WH-5683 **$8.95**
**10.0MM DIAMETER** WH-5684 **$10.95**
**16.0MM DIAMETER** WH-5685 **$14.95**
**20.0MM DIAMETER** WH-5686 **$21.95**

FROM $5.45

## Aerosols Spray Cans

Must have aerosols for all your electronic, automotive or field service.

**CIRCUIT BOARD LACQUER 175G** NA-1002 **$11.50**
**ELECTRONIC CIRCUIT BOARD CLEANER 175G** NA-1008 **$11.50**
**CONTACT CLEANER LUBRICANT 175G** NA-1012 **$11.50**
**INOX-MX3 CORROSION INHIBITOR 300G** NA-1024 **$11.50**

2 FOR $15

SAVE $8

**DOUBLE POINTS FOR REWARDS CARD HOLDERS ON THESE SECURITY CAMERAS & DVR***

*Valid for purchase of QC-8644, QC-8646, QC-8640, QC-8642 or QV-3039.

## Professional Surveillance Cameras

DOUBLE POINTS

Our latest generation of high resolution 960H cameras are your ideal choice of widescreen CCTV security cameras when designing a video surveillance system. All units are equipped with high quality sensors, are easy to install and will enable you to put the camera's field of view exactly where you need it. Unbeatable value!

**DOME** QC-8644 **$149** **BULLET** QC-8640 **$149**

**DOME** QC-8646 **$249** **BULLET** QC-8642 **$299**

**960HD**
HIGH DEFINITION VIDEO SURVEILLANCE

| | QC-8644 DOME | QC-8646 DOME | QC-8640 BULLET | QC-8642 BULLET |
|---|---|---|---|---|
| **Special Features** | 3-axis, IR LEDs | 3-axis varifocal camera with 3D gimbal mount, UTC, IR LEDs | 3-axis outdoor camera, UTC, IR LEDs | Varifocal outdoor camera, UTC, adjustable IR LEDs, long-range surveillance |
| **Sensor** | Sony 1/3" Super HAD II | Sony 1/3" Super HAD II | Sony 1/3" Super HAD II Effio-A | Sony 1/3" Super HAD II |
| **Sensor Resolution** | 976(H) x 582(V) | | | |
| **Resolution** | 800 TV Lines | | | |
| **Lens** | 3.6mm | 2.8-12mm Autoiris with ICR | 6.0mm | 9.0-22.0mm/F2.0 Autoiris with ICR |
| **IR Range** | 20m | 20m | 20m | 40m |
| **Waterproof** | Weatherproof | Weatherproof | IP66 | IP66 |
| **Power Consumption** | 340mA | 430mA | 390mA | 840mA |
| **Size** | 110(Dia) x 85mm | 110(Dia) x 85mm | 70 x 53 x 78mm | 180 x 106 x 110mm |

### 16-Channel Network DVR WITH 1TB HDD QV-3039

Build your surveillance system with this high performance network DVR which records in WD1 (960 x 576) resolution from all 16 camera inputs. Features multiple video output formats and remote viewing via a web browser or iPhone®/Smartphone app. Power supply included.

DOUBLE POINTS

- H.264 video compression
- HDMI connection
- Motion trigger recording
- 380(W) x 340(D) x 50(H)mm

*We also stock a wide range of 4 to 16-Channel standalone DVR & DVR kits. See website for more details.*

## GREAT FOR TV INSTALLERS

### 91 Element UHF TV Antenna LT-3182

Extremely well-priced high gain antenna with excellent performance on both analogue and digital TV signals. Suitable for deep fringe areas. 221mm long.

*Note: Mounting pole not included.*

- Receives Bands 4 and 5
- 15 to 19dB gain

**ALSO AVAILABLE: 43 ELEMENT UHF ANTENNA** for Medium Signal Areas LT-3181 **$44.95**

### Head Torches

Extremely bright 550 lumen Cree® LEDs with high, low and flashing/strobe light modes. Both lights feature an adjustable light beam and head strap.

**BATTERY** Requires 4 x AA batteries. ST-3298 **$29.95**

**RECHARGEABLE** Charger & mains included. ST-3299 **$49.95**

## HANDY PRODUCTS TO GET THE JOB DONE

### RS-232 DB9 to USB Micro-B Converter XC-4135

Connect legacy RS-232 equipped devices to your Android phone/Tablet with this clever device. Includes Micro-B USB power socket. 600mm long.

*See website for details.*

- Supported baud rates: 300 to 921600bps
- Compatible with Android 3.1 onwards

### N-Way Ethernet Switches

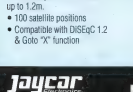
Unmanaged switches to enhance your network performance and efficiency. Supports auto-negotiation and cable length detection. Mains powered or via USB port.

- 8 x RJ-45 ports
- 13"(L) x 76(W) x 25(H)mm

**10/100MBPS SWITCH** YN-8077 **$24.95**

**10/100/1000MBPS GIGABIT SWITCH** YN-8078 **$59.95**

## FOR TRADIES ON THE ROAD

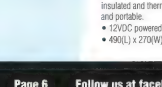



### DiSEqC™ Satellite Motor

LS-3330

Tough, high-grade and extremely simple to use from your satellite receiver with only one coaxial cable. Features adjustable hardware limits and suits dishes up to 1.2m.

- 100 satellite positions
- Compatible with DiSEqC 1.2 & Goto "X" function




### 14L Thermoelectric Cooler/Warmer GH-1373

Cools to 18-20°C below ambient temperature, and heats up to 65°C. Great for road trips and work sites. Low noise, fully insulated and thermoelectric. Lightweight and portable.

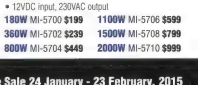
- 12VDC powered
- 490(L) x 270(W) x 305(H)mm

### 5W UHF CB Radio DC-1120

Compact under-dash unit with long transmission range up to 20km line of sight*. Features 80 channels, channel scan, repeater access, DTCSS, and signal strength meter. Microphone, lead and mounting bracket included.

**HIGH GAIN ANTENNA** to suit DC-1120. UHF 5dBi with 5m cable. DC-3078 **$79.95**

**Typical open field (line-of-sight) range will vary in built-up areas.*




### Portable Pure Sine Wave Inverters

Suitable for a variety of mobile and permanent power installations, these inverters offer standard protection (overload, high temperature, over/under input voltage and output short circuit) as well as host of additional features to improved performance and reliability under adverse conditions. Range from 180 to 2000W.

- USB port
- 12VDC input, 230VAC output

**180W** MI-5700 **$199** **1100W** MI-5706 **$599**

**360W** MI-5702 **$239** **1500W** MI-5708 **$799**

**800W** MI-5704 **$449** **2000W** MI-5710 **$999**

# BUILD YOUR OWN ARDUINO DATALOGGER

**TO RECORD LIGHT INTENSITY & TEMPERATURE MEASUREMENTS**

**DOUBLE POINTS for REWARDS CARD HOLDERS***

*Valid for purchase of RD-3485, RD-3480, ZL-3336, RB-0680, WC-6021, WC-6022, PB-8832, PB-8814, PB-8816, XC-4216 or XC-4989

# MUST HAVE TOOLS

**REWARDS CARD OFFER**

**BUY ALL 3 FOR $61.95***

**SAVE $12.90**

*Valid for purchase of TD-2122, TH-1810 & TS-1620

DOUBLE POINTS

**$2.75**

## Light Dependent Resistors

Cadmium Sulphide (CdS) light dependent resistor cells suitable for all your light-sensitive projects.

**2.8Ω TO 8.4Ω** RD-3485 **$2.75**

**48Ω TO 140Ω** RD-3480 **$2.75**

DOUBLE POINTS

**$3.95**

## Temperature Sensor

ZL-3336

Precise and easily-calibrated LM335Z TO-92 Linear IC with wide temperature range of -40°C to +100°C.

DOUBLE POINTS

**$14.95**

## Resistor Pack 300-Pieces

RR-0680

This assorted pack contains 5 of virtually each value from 10Ω to 1MΩ.

- 0.5W 1% mini size metal film

*See website for details*

**$6.95**

## Component Soldering Holder

TD-2122

Use this to hold small parts while soldering to avoid burnt fingers. Supplied with insulated handles. 65mm long.

**$7.95**

## Component Lead Forming Tool TH-1810

Get the hole spacing for your resistors and diodes perfect every time. This double-sided tool provides uniform hole spacing from 10 to 38mm. 138mm long. *Components not included.*

DOUBLE POINTS

**$3.95**

## Mixed 10-Piece Jumper Leads

For use in arduino projects, school experiments, or RC and other hobbyist activities.

**PLUG TO SOCKET/SOCKET TO SOCKET** 155mm long. WC-6021 **$3.95** (Shown)

**PLUG TO PLUG** 155mm long. WC-6022 **$3.95**

DOUBLE POINTS

FROM **$9.95**

## Solderless Breadboards

Three sizes of breadboards to suit all your project needs.

**300 TERMINAL HOLES** PB-8832 **$9.95**

**640 TERMINAL HOLES** PB-8814 **$19.95** (Shown)

**1280 TERMINAL HOLES** PB-8816 **$39.95**

**$59.95**



## 40W Soldering Station

TS-1620

An ideal temperature controlled soldering station with a lightweight iron and tip cleaning sponge to suit many projects.

- Temp range: 150°C to 450°C
- 135(L) x 82(W) x 70(H)mm

## EtherTen Board

XC-4216 **$69.95**

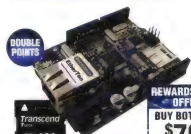
Combining an Arduino and an Ethernet shield onto one single board - includes onboard Ethernet, a USB-serial converter, and even Power-over-Ethernet support. Also features a microSD card slot for storing gigabytes of web server content or data.

- ATmega328P MCU running at 16MHz
- Built-in 10/100base-T Ethernet

**CLASS 10 16GB MICROSD CARD**

XC-4989 **$26.95**

DOUBLE POINTS

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*Valid for purchase of XC-4216 and XC-4989

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# ARDUINO ESSENTIALS

**$2.95**

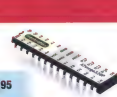
## Stackable Header Set

HM-3207

The perfect accessory to the ProtoShields and vero type boards when connecting to your Arduino compatible project.

- 2 x 8 pin and 2 x 6 pin included

**$9.95**



## ATmega328P Microcontroller

ZZ-8726

An Atmel AVR ATmega328P microcontroller to build customised Arduino compatible projects. Includes 16MHz crystal oscillator.

- Pre-installed Arduino Uno bootloader

**$24.95**

## ICSP Programmer

XC-4237

Program new applications into a wide range of microcontrollers using this ICSP programmer with a USB interface. Compatible with a wide range of microcontrollers, including all Arduino boards.

- Compatible with Windows, Mac, and Linux

**$24.95**

## LED Pack 100-Pieces

ZD-1694

This assorted pack contains 3mm and 5mm LEDs of mixed colours. Even includes 10 x 5mm mounting hardware FREE! See website for more details.

- Red, green, yellow, orange LEDs

**$4.95**

## ProtoShield Short XC-4248

A dedicated short version prototyping shield for EtherTen (XC-4216) and EtherMega (XC-4256) and designed to fit neatly behind the RJ45 Ethernet jack.

- 49(W) x 54(H) x 2(D)mm

**$19.95**

## Temperature/Humidity Sensor

XC-4246

Measures temperature and relative humidity using a simple interface that requires just three wires to the sensor; GND, power, and data.

- Temperature: -4°C to +125°C (±0.5°C)
- Humidity: 0 to 100% (±2-5%)

**$29.95**

## 16x2 LCD Shield XC-4218

This handy 16-character by 2-line display plugs straight into your Arduino with 5 buttons for user input.

- Software-controlled blue backlight
- Can be panel mounted if required
- 85(W) x 54(H) x 12(D)mm

**$34.95**

## Light Duty Hook-up Wire Pack - 8 colours

WH-3009

Quality tinned hook-up wire on plastic spools. 8 rolls included, each roll a different colour.

- 25m on each roll

# EASY ON THE JOB, EASY ON THE WALLET
# NEW LOW PRICES UP TO 55% OFF

Below are a number of discontinued (but still good) items that we can no longer afford to hold stock. Please ring your local store to check stock.
At these prices we won't be able to transfer from store to store. **STOCK IS LIMITED. ACT NOW TO AVOID DISAPPOINTMENT. SORRY NO RAINCHECKS.**

**$6.95** SAVE $3

### 12VDC Voltage Polarity Easy Tester

QP-2215 **ORRP $9.95**

This handy little device is quick, easy and performs many essential field tests. Ideal for CCTV & security installers, car audio, roadies, AV techs etc.

- Voltage, load, polarity, voltage drop and PTC tests
- 51(L) x 44(W) x 29(D)mm

**$53.95** SAVE $65.05

### Non-Contact Thermometer GM-7211 **ORRP $119**

Easy way to measure and compare temperatures. Simply set a reference temperature and make comparisons on different surfaces. Also has audible and visual warnings when exceeding or dropping below reference point.

- Flip up display, dual laser targeting data hold etc.
- 170(H) x 125(D) x 67(W)mm

*See website for features and specifications.*

*iPhone not included.*

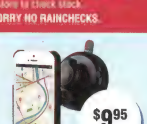
**$119** SAVE $30

### Wi-Fi Inspection Camera For Smartphones

QC-3351 **ORRP $149**

Inspect the inaccessible areas with this 1.8" colour CMOS camera. Uses your Smartphone as the screen. Power supply, bracket, hook and metal adaptor included.

- IP67 rated camera
- 685mm flexible gooseneck
- Up to 50m line-of-sight range



*iPhone not included.*

**$9.95** SAVE $10

### Universal Suction Mount Bracket For Smartphones

HS-9014 **ORRP $19.95**

This handy bracket mounts your Smartphone on the windscreen or dashboard of the vehicle and gives you an extra hand for navigation, music or communication.

- Strong 70mm diameter suction mount
- Ball and socket joint allows optimum viewing angle
- Includes iPhone® 4/4S/5 and universal brackets

## LIGHT UP!

### LED Dimmable Light Globes

**ORRP $29.95 EA.**
**NOW $19.95 EA. SAVE $10**

A range of dimmable mains LED light globes that is a true replacement for traditional lighting, offering brilliant lumen performance with wide and evenly spread light.

- 270 degree spread
- 10W, equivalent to a 75W traditional globe

**620 LUMENS** Warm White Bayonet SL-2214*
**820 LUMENS** Warm White Screw SL-2215*
**900 LUMENS** Natural White Bayonet SL-2216*
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REWARDS CARD OFFER
BUY 4 FOR **$50*** 
SAVE $69.80

## EXTRA SAVINGS FOR REWARDS CARD HOLDERS

### Solar Rechargeable LED Spotlight

ST-3312
**ORRP $39.95**
**NOW $24.95 SAVE $15**

This super bright 140 lumens spotlight is extremely versatile with its dual position swivel handle and a detachable solar cell to allow charging almost anywhere. Includes car cigarette lighter and mains chargers.

- Up to 3 hours burn time

REWARDS CARD OFFER
BUY 3 FOR **$65†**
SAVE $54.85

† *Valid with purchase of ST-3312*

### 12V LED Worklight

ST-3264
**ORRP $29.95 NOW $23.95 SAVE $6**

60 super bright LEDs housed in a polycarbonate lens. IP65 rated with PVC casing, 3m curly cord with cigarette lighter plug.

- Strong rear magnet and swivel hook
- 450mm Long

REWARDS CARD OFFER
BUY 3 FOR **$60†**
SAVE $29.85

† *Valid with purchase of ST-3264*

**$19.95** SAVE $20

### In-Car FM Transmitter Kit

AR-3104 **ORRP $39.95**

Simply plugs into a cigarette lighter socket and will play audio tracks from a SD/MMC card, USB flash drive, iPod®, or MP3 player directly through the FM band on the car stereo. Remote control included.

- Includes 4m long in-line antenna for drift-free FM transmission

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*Prices valid from 24 January - 23 February, 2015.*

*We've covered the theory – now here's how to build it!*

# SPARK ENERGY METER

Design by
Dr Hugo Holden

**This meter closely estimates the energy delivered to actual sparks in the ignition system under test, either a CDI or MDI system.**

**Earlier in this issue, we described the ideal way** to measure the output of an ignition system: to load it with a bidirectional 1000V zener diode which approximates the actual voltage drop when a spark is established. Our meter actually uses a 1500V zener which gives similar results, for reasons explained below.

The meter has two ranges which are selected automatically, zero to 100 millijoules or zero to 1000mJ and it can work with a spark repetition rate up to 700 sparks per second (corresponding to more than 10000 RPM in a V8 engine) or down to just 1Hz. It can measure uni-polar or bi-polar spark voltages.

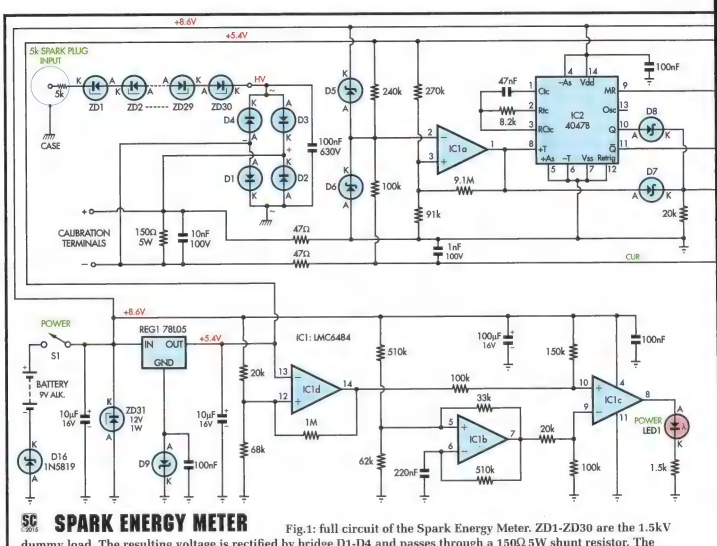
The meter is portable and battery-powered. It also has a low battery indicator. It can be connected to a working engine one spark plug at a time or alternatively, it can be used to bench test an ignition system.

It works with single or double-ended ignition coils.

## Circuit description

Fig.1 shows the complete circuit. The HT connection from the ignition system is applied to a spark plug which is a 5kΩ resistor type, BR8HS. The plug's earth part of the electrode is cut off and the plug is used as a feed through connector.

The 5kΩ resistor in the plug helps to limit and isolate very brief high current transients caused by the stray and




## SPARK ENERGY METER

**Fig.1: full circuit of the Spark Energy Meter. ZD1-ZD30 are the 1.5kV dummy load. The resulting voltage is rectified by bridge D1-D4 and passes through a 150Ω 5W shunt resistor. The output is is integrated by IC3b while a sample & hold buffer comprising IC5b-IC5d and IC3c provide a steady signal for the LCD meter. Q1 discharges the hold capacitor if the spark train ceases while IC3d and IC4a switch the unit to a higher range for more energetic sparks. IC1b-IC1d monitor the battery voltage and flash LED1 if it's low.**

distributed capacitance of the ignition coil, distributor and the wiring.

The high voltage signal from the plug is fed to a string of 30 100V 5W zener diodes, wired to create a high-voltage, high-power bidirectional 1500V zener diode.

The reason an effective or equivalent spark sustaining voltage of 1500V was chosen rather than 1000V is so that signal processing of the "Dwell Artefact" is avoided when testing ignition coils directly.

Also it accounts for the 500V spark voltage drop in the distributor in a conventional ignition system and in fact, the spark energy delivered at 1500V is similar to that at 1000V in any case.

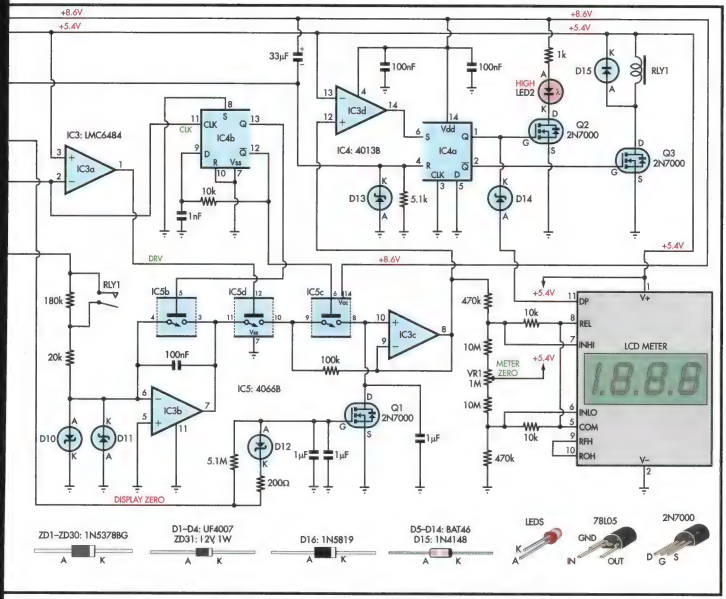
After passing through the bidirectional zener diode assembly, the signal is fed to a bridge rectifier (diodes D1 to D4) with a 100nF capacitor across it, to suppress short-term variations in voltage. Its output goes to a 150Ω 5W current-sense resistor shunted by a 10nF capacitor to provide further filtering.

Neither capacitor significantly affects the signal waveform or the signal's integrated value.

The voltage across the 150Ω 5W resistor is proportional to the spark current. The top end of this resistor is

## Specifications

| | |
|---|---|
| Range: | 0-100mJ (low range), 0-1000mJ (high range, automatic switching) |
| Input: | standard spark plug connection with separate earthing lead |
| Measurement Linearity: | ~4% |
| Power supply: | 9V alkaline battery (internal), ~17mA drain |
| Low voltage indication: | power LED flashes below ~7.2V |
| Calibration: | onboard display zeroing and scale adjustment. (Scale is set accurately using a calibrator board, described below.) |




connected to circuit ground via a 47Ω resistor while the negative end goes to the inverting input of op amp IC3b via an RC low-pass filter (47Ω & 1nF) and a series-connected pair of resistors (180kΩ + 20kΩ).

IC3b operates as the integrator at the heart of this circuit. To measure the energy of the spark, we need to calculate the product of the voltage across the dummy load (fixed at 1500V) with the integral of load current over time. Another way to think of this integral is as the area under a curve plotting current against time. Luckily a simple op amp integrator performs this calculation for us.

IC3b uses a 100nF integrator capacitor which is reset to 0V before each spark and charges at a rate proportional to spark current. The voltage across the 150Ω resistor is Ispk x 150. Ignoring the 180kΩ series resistor (which is initially shorted out by reed relay RLY1), the combination of a 20kΩ resistor and 100nF capacitor gives an output at pin 7 of Ispk x 150÷ (20kΩ x 100nF) = 75000V/A.s or 75V/mA.s. Given the constant 1500V load voltage, this is equivalent to 50V/J (75000V / 1500V, 1J = 1V.A.s).

Thus, the maximum output we can expect from rail-to-rail op amp IC3b running from a 9V battery is around 5V, representing 100mJ.

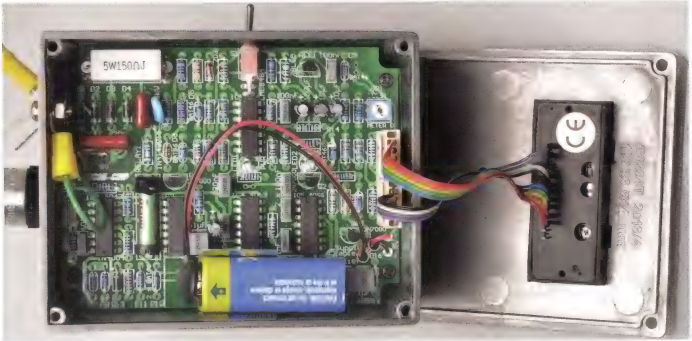
To take higher readings, RLY1 switches off (as explained later) and this increases the source resistance of IC3b from 20kΩ to 200kΩ, reducing its sensitivity to 5V/J and thus readings up to 1J are possible.

Note that because the shunt voltage is applied to a bridge rectifier before being fed to IC3b, both positive and negative spark voltages contribute to the reading.

## Sample and hold

Because the spark duration is quite short but we want a steady reading on the display, the circuit incorporates sample and hold. The energy of every second spark is measured and once the reading is complete, it is "latched" in the hold buffer as soon as the next spark is detected, resulting in a steady reading on the LCD panel meter (assuming the spark energy is relatively consistent).

Op amp stage IC1a is used to detect the start of each spark. Its non-inverting input, pin 3, has a reference voltage of 1.35V applied, generated by the 270kΩ/91kΩ resistive divider across the 5.4V regulated supply rail. The inverting input, pin 2 normally sits at




**Just a little smaller than life-size, this inside shot shows how the PCB fits inside the diecast case, with the display mounted on the lid At left, just in view, is the base of the spark plug used as a termination point, along with the earth connection and double lug. Construction details will be provided in the second part of this project, next month.**

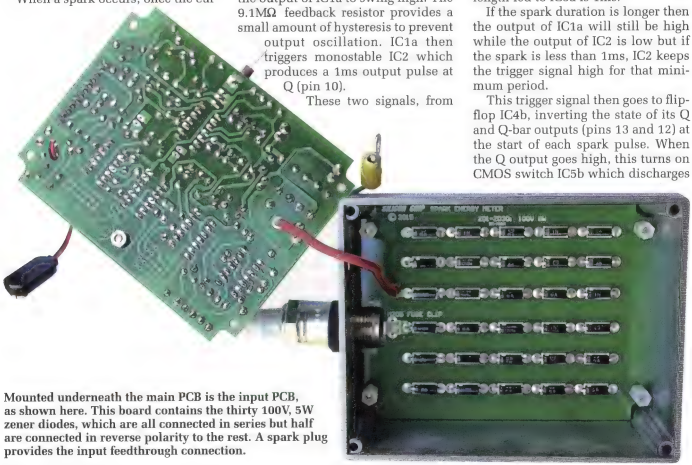
around 1.6V due to the 240kΩ / 100kΩ divider between the 5.4V rail and the bottom of the sense resistor, which is at ground potential between sparks.

When a spark occurs, once the current rises above about 3mA, this causes a voltage of 0.45V across the sense resistor and thus the voltage at pin 2 of IC1a drops below 1.3V, causing the output of IC1a to swing high. The 9.1MΩ feedback resistor provides a small amount of hysteresis to prevent output oscillation. IC1a then triggers monostable IC2 which produces a 1ms output pulse at Q (pin 10).

These two signals, from IC1a and IC2, are "ORed" by diodes D7 and D8 in combination with the 20kΩ pull-down resistor. The purpose of IC2 is to ensure that the minimum pulse length fed to IC3a is 1ms.

If the spark duration is longer then the output of IC1a will still be high while the output of IC2 is low but if the spark is less than 1ms, IC2 keeps the trigger signal high for that minimum period.

This trigger signal then goes to flip-flop IC4b, inverting the state of its Q and Q-bar outputs (pins 13 and 12) at the start of each spark pulse. When the Q output goes high, this turns on CMOS switch IC5b which discharges



**Mounted underneath the main PCB is the input PCB, as shown here. This board contains the thirty 100V, 5W zener diodes, which are all connected in series but half are connected in reverse polarity to the rest. A spark plug provides the input feedthrough connection.**

## Spark Energy Meter: Parts List

1 double-sided PCB, code 04102151, 110.5 x 85mm
1 double-sided PCB, code 04102152, 110.5 x 85mm
1 front panel label 109 x 84mm
1 diecast box 119 x 94 x 57mm (Jaycar HB-5064 or equivalent)
1 LCD panel meter (Jaycar QP-5570 or equivalent)
1 5V reed relay (Jaycar SY-4036 or equivalent) (RELAY1)
1 SPDT PCB mount toggle switch (Altronics S1421 or equivalent) (S1)
1 resistive spark plug 14mm thread and preferably 12.7mm reach or similar (BR8HS)
1 9V U clip battery holder (Jaycar PH-9237, Altronics S 5050)
1 9V battery snap and lead
1 9V alkaline battery
1 TOP-3 silicone washer
2 6-way polarised headers with 2.54mm spacings (Jaycar HM-3406 or equivalent)
2 6-way header plugs with 2.54mm spacings (Jaycar HM-3416 or equivalent)
8 stick-on rubber feet
1 alligator clip (Jaycar HM-3025 or equivalent)
1 M4 x 10mm screw
1 M4 nut
1 4mm star washer
1 crimp eyelet (1mm diameter cable entry)
1 6.3mm chassis spade connector
1 6.3mm crimp female spade connector (1mm diameter cable entry)
1 M3 x 6mm countersunk screw
1 M3 nut
4 M3 x 12mm countersunk screws
8 M3 tapped Nylon spacers
4 M3 x 5mm machine screws
1 100mm length of 9-way rainbow cable
1 200mm length of 7.5A mains-rated cable
1 1m length of 7.5A green or black mains rated cable
1 200mm length of 4mm diameter heatshrink tubing
1 M205 fuse clip
2 PC stakes
1 1MΩ horizontal trimpot (VR1)

**Semiconductors**

2 LMC6484AIN quad CMOS op amps (IC1, IC3)
1 4047B monostable/astable multivibrator (IC2)
1 4013B dual D flipflop (IC4)
1 4066B quad CMOS switch (IC5)
1 78L05 low power 5V regulator
3 2N7000 N channel FETs (Q1-Q3)
30 1N5378BG 100V 5W zener diodes (ZD1-ZD30)
1 12V 1W zener diode (ZD31)
4 UF4007 1A 1000V fast diodes (D1-D4)
10 BAT46 Schottky diodes (D5-D14)
1 1N4148 switching diode (D15)
1 1N5819 1A Schottky diode (D16)
2 3mm LEDs (LED1,LED2)

**Capacitors**

1 100µF 16V electrolytic
1 33µF 16V electrolytic
2 10µF 16V electrolytic
3 1µF MKT
1 220nF MKT
6 100nF MKT
1 100nF 630V polyester (greencap)
1 47nF MKT
1 10nF 630V polyester (greencap) or 3kV ceramic
1 1nF 1kV ceramic (Altronics R2889)
1 1nF MKT

**Resistors** (0.25W, 1%)

| | |
|---|---|
| 2 10MΩ | 1 68kΩ |
| 1 9.1MΩ | 1 62kΩ |
| 1 5.1MΩ | 1 33kΩ |
| 1 1MΩ | 4 20kΩ |
| 2 510kΩ | 3 10kΩ |
| 2 470kΩ | 1 8.2kΩ |
| 1 270kΩ | 1 5.1kΩ |
| 1 240kΩ | 1 1.5kΩ |
| 1 180kΩ | 1 1kΩ |
| 1 150kΩ | 1 200Ω |
| 4 100kΩ | 1 150Ω 5W |
| 1 91kΩ | 2 47Ω |

### Parts List For Calibrator

1 PCB, code 05101153, 47 x 61mm
2 2-way screw terminals with 5.08mm spacings
1 25mm length of 0.7mm tinned copper wire
3 PC stakes
1 100Ω horizontal trimpot (VR1)
1 50kΩ horizontal trimpot (VR2)

**Semiconductors**

1 7555 CMOS timer (IC1)
1 LM317T adjustable 3-terminal regulator (REG1)
1 IRF540 N-channel Mosfet (Q1)
1 BC337 NPN transistor (Q2)
1 BC327 PNP transistor (Q3)
2 1N4004 1A diodes (D2)

**Capacitors**

1 100µF 16V electrolytic
2 10µF 16V electrolytic
1 100nF MKT
1 10nF MKT

**Resistors** (0.25W, 1%)

| | |
|---|---|
| 1 220kΩ | 1 100Ω |
| 1 240Ω | 1 10Ω |

### Alternative PWM circuit

2 1N4148 diodes (D3,D4)
1 1kΩ resistor in place of 220kΩ
1 250kΩ horizontal trimpot (VR2)

the integrator capacitor, thus resetting it.

When the next spark occurs, the Q output goes low, releasing this reset and at the same time, Q-bar goes high, switching on IC5c which allows the output of IC3b (the integrator) to charge the 1µF capacitor at the input of buffer IC3c.

However, note that CMOS switch IC5d also must be enabled for this capacitor to charge and that is driven by op amp stage IC3a, configured as an inverter to invert the pulses from IC2. Hence, the sample-and-hold buffer only samples the output of the integrator after the spark duration and thus the integration of the spark current has been completed.

The 100kΩ resistor from the output of buffer IC3c to pin 9 of IC5c prevents leakage current through IC5c from slowly discharging the 1µF capacitor.

The output of IC3c therefore is a steady voltage representing the last energy value computed by the integrator and this is fed to the LCD panel meter via a resistive divider network with VR1 providing a zeroing adjustment.

The resistors chosen set the correct full scale reading for the meter, so that with 5V at the output of IC3c, it will read either 100.0 (at 100mJ full-scale

mode) or 1000 (at 1J full-scale mode).

## Auto-ranging

As we mentioned earlier, reed relay RLY1 is initially switched on to provide the more sensitive 100mJ full-scale reading. Op amp IC3d is wired to compare the output of sample-and-hold buffer IC3c's output to the 5.4V rail.

Thus once the reading goes above 108mJ, its output goes high, setting flipflop IC4a. IC4a is initially reset by the 33µF capacitor and 5.1kΩ resistor at its pin 4 input, with D13 discharging the capacitor at switch-off (this same signal also resets IC2 initially).

With IC4a reset, its Q output at pin 1 is low and thus Q2 is off, so the high-range indicator LED (LED2) is also off. At the same time, the Q-bar output at pin 2 is high, so Q3 is switched on and this powers the coil of RLY1.

When the output of IC3d goes high and the flip-flop is set, LED2 switches on and RLY1 switches off. The only way to return to the higher-sensitivity 100mJ scale mode is to switch the unit off and on again, resetting IC4a.

## Display zeroing

Ideally, when sparks are no longer being delivered to the unit, the display shouldn't just hold the last reading forever. We want it to drop to zero so we realise that there are no more sparks being detected (and thus no energy being measured). This is achieved by Mosfet Q1 which discharges the 1µF hold capacitor after a few seconds without any spark pulses.

The Q-bar output of IC2 goes low for 1ms on every second spark detected, discharging the two 1µF capacitors at Q1's gate and thus keeping it off. However, if the sparks stop for long enough, these capacitors charge via the 5.1MΩ resistor and thus Q1 switches on, zeroing the reading.

## Power supply

The unit is powered from a single 9V alkaline battery. Reverse polarity protection is provided by Schottky diode D16 while power switch S1 turns the unit on and off. 78L05 regulator REG1 has a Schottky diode in its ground leg to "jack up" its output to 5.4V. This is to ensure that it's always above the output of IC3c even with the meter at its maximum reading of 100mJ/1J, which corresponds to 5V.

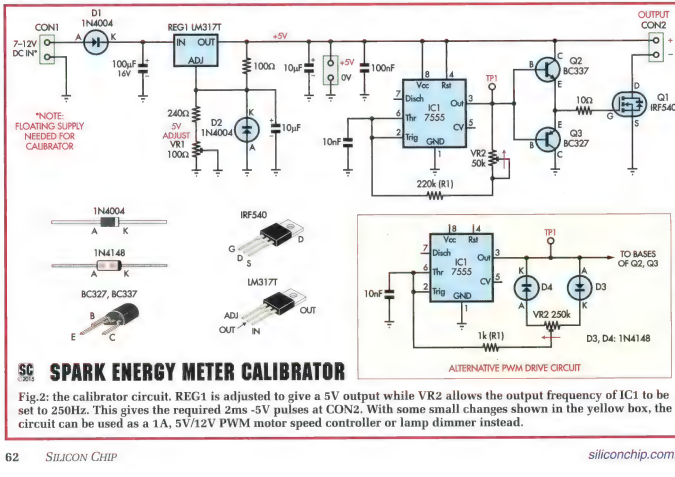
Op amp stages IC1b-IC1d provide a low battery warning which flashes power indicator LED1 if the battery voltage drops below 7.2V. IC1d is the low-battery comparator, with its inverting input (pin 13) connected to the 5.4V rail as a reference and pin 12 connected to a voltage divider across the battery. A 1MΩ positive feedback resistor provides hysteresis.

If the battery level is low, the output of IC1d goes low, reducing the voltage at input pin 10 of IC1c. This op amp acts as an OR-gate, so while the battery voltage is above the 7.2V threshold, its output is always high and thus power LED1 is lit constantly.

But once the voltage at pin 10 drops, astable oscillator IC1b driving its pin 9 input and causes the output to pulse, flashing LED1. The 510kΩ and 220nF component values at IC1b's inverting input (pin 6) in combination with the resistors connected to its pin 5 non-inverting input. set the flash rate to around 2Hz with a duty cycle of around 75%.

## Calibrator circuit

The meter must be calibrated before use to ensure accuracy and this is done by by applying a test signal with a repetitive 2ms -5V pulse across the 150W 5W resistor. The display is then calibrated to show 100mJ. This is done by adjusting the internal trimmer on the LCD. We've designed




SC 2015 **SPARK ENERGY METER CALIBRATOR**

**Fig.2: the calibrator circuit. REG1 is adjusted to give a 5V output while VR2 allows the output frequency of IC1 to be set to 250Hz. This gives the required 2ms -5V pulses at CON2. With some small changes shown in the yellow box, the circuit can be used as a 1A, 5V/12V PWM motor speed controller or lamp dimmer instead.**

a PCB to perform this task and the circuit is shown in Fig.2. Once you've finished using it to calibrate the Spark Energy Meter, it can be reconfigured to operate as a pulse width modulated (PWM) DC speed controller.

Since a 2ms pulse is required, the simple solution is to generate a 250Hz square wave with the required amplitude. If the duty cycle is close to 50%, the frequency and voltage can be adjusted to the correct values using measurements from a DMM.

The circuit operates from a 7-12V supply with reverse polarity protection by diode D1. REG1 is an adjustable regulator that is adjusted to give exactly 5V. Typically, the voltage between the OUT and ADJ terminal is 1.25V but could range between 1.2 and 1.3V depending on the particular regulator.

The 100Ω resistor between the output and adjust terminal sets a nominal 12.5mA flowing through the 240Ω resistor and 100Ω trimpot. That current will allow the adjust terminal to be set to sufficient voltage for 5V at the output.

CMOS timer IC1 runs from this 5V supply. It has a rail-to-rail output at pin 3. That means the output will swing to a few millivolts off 5V when pin 3 is high and to a few millivolts shy of 0V when the output is low. The output drives resistances VR2 and the 220k resistor in series to charge the 10nF capacitor connected to pins 2 & 6 when pin 3 is high and discharge when pin 3 is low.

When the pin 3 output is high, this capacitor charges to 2/3rds the supply voltage, whereupon pin 6 detects this and sets the output low, discharging the capacitor. When the capacitor reaches 1/3rds the supply voltage, pin 2 detects this and the pin 3 output goes high. The cycle continues, alternately charging and discharging the capacitor.

Since the capacitor is charged and discharged symmetrically between 1/3rds and 2/3rds the supply voltage via the same value resistance, the pin 3 output is a square wave with a 50% duty cycle.

The pin 3 output also drives emitter-follower buffer transistors Q2 and Q3 to drive the gate of Mosfet Q1 via a 10Ω resistor. When pin 3 is high, Q2 is switched on to charge Q1's gate, switching it on in turn. When pin 3 is low, Q3 switches on instead and the Mosfet's gate is discharged, turning it off.

The 5V supply rail and drain of the Mosfet are connected to the 150Ω resistor in the Spark Energy Meter via CON2 to provide the calibration signal. Note that the supply for the calibrator needs to be floating relative to that of the Spark Energy Meter. So long as the same 9V battery is not used to power both circuits, that will be the case. The two circuits should not be joined except via CON2.

## Alternative circuit

The circuit diagram shows an alternative circuit that could be used after the Spark Energy Meter has been calibrated. You can then use this circuit as a pulse width modulated power control for small DC motors or for lamps up to about 1A. The motor needs to be rated for 5V. For a higher voltage motor, you can connect between the minus terminal of CON2 and the + terminal of CON1 to run at the input supply voltage (eg, 12V).

In this configuration, the 220kΩ resistor is replaced with a 1kΩ resistor and VR2 is replaced by a 250kΩ type. Diodes D3 and D4 are added so there will be a different charge and discharge path. When pin 3 is high, the 10nF capacitor is charged via D3 and the portion of VR2 to its wiper. During discharge, the capacitor is discharged via diode D4 and the opposite portion of VR2 to the wiper. So if VR2 is set to its mid point, the waveform should be close to a square wave as the resistance on either side of the trimpot wiper are the same.

The more VR2 is adjusted off centre the more the waveform becomes asymmetric. At the extremes of VR2, the output will be high for the ratio of 1/250 of each cycle when the wiper is wound anticlockwise and high for 249/250 when the wiper is fully clockwise. That way the Mosfet can be switched to be on almost all the time or off most of the time or anywhere in between.

## Next month

In the part 2 article next month, we'll go through building the three PCBs, assembling the two main boards into the diecast case and the calibration and set-up procedure.

We'll also go over how to connect the spark energy meter to a working engine. SC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| | | |
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| **10A 230V AC MOTOR SPEED CONTROLLER** | *(Feb14)* | **$45.00** |
| 40A IGBT, 30A Fast Recovery Diode, IR2125 Driver and NTC Thermistor | | |
| **GPS Tracker** MCP16301 SMD regulator IC and 15µH inductor | *(Nov13)* | **$5.00** |
| **SMD parts for SiDRADIO** | *(Oct13)* | **$20.00** |
| **RF Probe** All SMD parts | *(Aug13)* | **$5.00** |
| Same as LF-UF Upconverter parts but includes 5V relay and BF998 dual-gate Mosfet. | | |
| **LF-HF Up-converter** Dmnon G5V-1 5V SPDT 5V relay | *(Jun13)* | **$2.00** |
| **"JUMP IN COAX" MINI MODEM** SMD parts kit: | *(Jun13)* | **$20.00** |
| Includes: 2 x OPA4348AID, 1 x BQ2057CSN, 2 x DMP2215L, 1 x BAT54S, 1 x 0.22Ω shunt | | |
| **LF-HF UP-CONVERTER** SMD parts kit: | *(Jun13)* | **$15.00** |
| Includes: FXO-HC536R-125 and SA602AD and all SMD passive components | | |
| **CLASSIC DAC** Semi kit – includes three hard-to-get SMD ICs: | *(Feb-May13)* | **$45.00** |
| CS8416-CZZ, CS4398-CZZ and PLL1708DBQ plus an accurate 27MHz crystal and ten 3mm blue LEDs with diffused lenses | | |
| **ISL9V5036P3 IGBT** Used in high energy ignition and Jacob's Ladder *(Nov/Dec12, Feb13)* | | **$10.00** |
| **2.5GHz Frequency Counter** | *(Dec12/Jan13)* | |
| *LCD kit:* 2 x 4-digit blue LED displays | | **$15.00** |
| *MMC & Choke Kit:* ERA-2SM+ Wideband MMC and ADCH-80+ Wideband Choke | | **$15.00** |
| **ZXCT1009 Current Shunt Monitor IC** | *(Oct12)* | **$5.00** |
| As used in DCC Reverse Loop Controller/Block Switch (Pack of 2) | | **$7.50** |

**All items subject to availability.* Prices valid for month of magazine issue only. All prices in Australian dollars and included GST where applicable.

***# P&P prices are within Australia. Oseas? Please email for a quote***

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# PRINTED CIRCUIT BOARDS

**NOTE: These listings are for the PCB only – *not a full kit*. If you want a kit, contact the kit suppliers advertising in this issue.**

| PRINTED CIRCUIT BOARD TO SUIT PROJECT: | PUBLISHED: | PCB CODE: | Price: |
|---|---|---|---|
| ELECTROLYTIC CAPACITOR REFORMER | AUG 2010 | 04108101 | **$40.00** |
| ULTRASONIC ANTI-FOULING FOR BOATS | SEP 2010 | 04109101 | $25.00 |
| HEARING LOOP RECEIVER | SEP 2010 | 01209101 | $25.00 |
| S/PDIF/COAX TO TOSLINK CONVERTER | OCT 2010 | 01210101 | $10.00 |
| TOSLINK TO S/PDIF/COAX CONVERTER | OCT 2010 | 01210102 | $10.00 |
| DIGITAL LIGHTING CONTROLLER MASTER UNIT | OCT 2010 | 16110101 | **$10.00** |
| DIGITAL LIGHTING CONTROLLER SLAVE UNIT | OCT 2010 | 16110102 | **$25.00** |
| HEARING LOOP TESTER/LEVEL METER | NOV 2010 | 01111101 | $25.00 |
| UNIVERSAL USB DATA LOGGER | DEC 2010 | 04112101 | $25.00 |
| HOT WIRE CUTTER CONTROLLER | DEC 2010 | 18112101 | $10.00 |
| 433MHZ SNIFFER | JAN 2011 | 06101111 | $10.00 |
| CRANIAL ELECTRICAL STIMULATION | JAN 2011 | 99101111 | **$25.00** |
| HEARING LOOP SIGNAL CONDITIONER | JAN 2011 | 01101111 | **$25.00** |
| LED DAZZLER | FEB 2011 | 16102111 | **$15.00** |
| 12/24V 3-STAGE MPPT SOLAR CHARGER | FEB 2011 | 14102111 | $5.00 |
| SIMPLE CHEAP 433MHZ FEEDER | FEB 2011 | 06102111 | $5.00 |
| THE MAXIMITE | MAR 2011 | 06103111 | **$15.00** |
| UNIVERSAL VOLTAGE REGULATOR | MAR 2011 | 18103111 | **$10.00** |
| 12V 20-120W SOLAR PANEL SIMULATOR | MAR 2011 | 04103111 | **$10.00** |
| MICROPHONE NECK LOOP COUPLER | MAR 2011 | 01209101 | $25.00 |
| PORTABLE STEREO HEADPHONE AMP | APRIL 2011 | 01104111 | **$10.00** |
| CHEAP 100V SPEAKER/LINE CHECKER | APRIL 2011 | 04104111 | $10.00 |
| PROJECTOR SPEED CONTROLLER | APRIL 2011 | 13104111 | $10.00 |
| SPORTSYNC AUDIO DELAY | MAY 2011 | 01105111 | $30.00 |
| 100W DC-DC CONVERTER | MAY 2011 | 11105111 | **$15.00** |
| PHONE LINE POLARITY CHECKER | MAY 2011 | 12105111 | $10.00 |
| 20A 12/24V DC MOTOR SPEED CONTROLLER MK2 | JUNE 2011 | 11106111 | **$15.00** |
| USB STEREO RECORD/PLAYBACK | JUNE 2011 | 07106111 | **$20.00** |
| VERSATIMER/SWITCH | JUNE 2011 | 19106111 | $25.00 |
| USB BREAKOUT BOX | JUNE 2011 | 04106111 | $10.00 |
| ULTRA-LD MK3 200W AMP MODULE | JULY 2011 | 01107111 | $25.00 |
| PORTABLE LIGHTNING DETECTOR | JULY 2011 | 04107111 | **$15.00** |
| RUDDER INDICATOR FOR POWER BOATS (4 PCBs) | JULY 2011 | 20107111-4 | $80 per set |
| VOX | JULY 2011 | 01207111 | **$20.00** |
| ELECTRONIC STETHOSCOPE | AUG 2011 | 01108111 | **$10.00** |
| DIGITAL SPIRIT LEVEL/INCLINOMETER | AUG 2011 | 04108111 | $10.00 |
| ULTRASONIC WATER TANK METER | SEP 2011 | 04109111 | $10.00 |
| ULTRA-LD MK2 AMPLIFIER UPGRADE | SEP 2011 | 01209111 | $5.00 |
| ULTRA-LD MK3 AMPLIFIER POWER SUPPLY | SEP 2011 | 01109111 | $25.00 |
| HIFI STEREO HEADPHONE AMPLIFIER | SEP 2011 | 01309111 | **$20.00** |
| GPS FREQUENCY REFERENCE (IMPROVED) | SEP 2011 | 04103073 | **$15.00** |
| GPS FREQUENCY REFERENCE DISPLAY (B) | SEP 2011 | 04103072 | $15.00 |
| HEARING LOOP RECEIVER/NECK COUPLER | SEP 2011 | 01209101 | **$10.00** |
| DIGITAL LIGHTING CONTROLLER LED SLAVE | OCT 2011 | 16110111 | $30.00 |
| USB MIDIMATE | OCT 2011 | 23110111 | **$25.00** |
| QUIZZICAL QUIZ GAME | OCT 2011 | 08110111 | **$20.00** |
| ULTRA-LD MK3 PREAMP & REMOTE VOL CONTROL | NOV 2011 | 01111111 | $30.00 |
| ULTRA-LD MK3 INPUT SWITCHING MODULE | NOV 2011 | 01111112 | **$20.00** |
| ULTRA-LD MK3 SWITCH MODULE | NOV 2011 | 01111113 | $10.00 |
| ZENER DIODE TESTER | NOV 2011 | 04111111 | $20.00 |
| MINIMAXIMITE | NOV 2011 | 07111111 | $10.00 |
| ADJUSTABLE REGULATED POWER SUPPLY | DEC 2011 | 18112111 | $5.00 |
| DIGITAL AUDIO DELAY | DEC 2011 | 01212111 | **$25.00** |
| DIGITAL AUDIO DELAY Front & Rear Panels | DEC 2011 | 01212112/3 | $20 per set |
| AM RADIO | JAN 2012 | 08101121 | $10.00 |
| STEREO AUDIO COMPRESSOR | JAN 2012 | 01201121 | $30.00 |
| STEREO AUDIO COMPRESSOR FRONT & REAR PANELS | JAN 2012 | 01201121P1/2 | $20.00 |
| 3-INPUT AUDIO SELECTOR (SET OF 2 BOARDS) | JAN 2012 | 01101121/2 | $30 per set |
| CRYSTAL DAC | FEB 2012 | 01102121 | $20.00 |
| SWITCHING REGULATOR | FEB 2012 | 18102121 | $5.00 |
| SEMTEST LOWER BOARD | MAR 2012 | 04103121 | $40.00 |
| SEMTEST FRONT PANEL | MAR 2012 | 04103123 | $75.00 |
| INTERPLANETARY VOICE | MAR 2012 | 08102121 | $10.00 |
| 12/24V 3-STAGE MPPT SOLAR CHARGER REVA | MAR 2012 | 14102112 | $10.00 |
| SOFT START SUPPRESSOR | APR 2012 | 10104121 | $10.00 |
| RESISTANCE DECADE BOX | APR 2012 | 04104121 | $20.00 |
| RESISTANCE DECADE BOX PANEL/LID | APR 2012 | 04104122 | $20.00 |
| 1.5kW INDUCTION MOTOR SPEED CONT. (NEW V2 PCB) | APR (DEC) 2012 | 10105122 | $35.00 |
| HIGH TEMPERATURE THERMOMETER MAIN PCB | MAY 2012 | 21105121 | $30.00 |
| HIGH TEMPERATURE THERMOMETER Front & Rear Panels | MAY 2012 | 21105122/3 | $20 per set |
| MIX-IT! 4 CHANNEL MIXER | JUNE 2012 | 01106121 | $20.00 |
| PIC/AVR PROGRAMMING ADAPTOR BOARD | JUNE 2012 | 24105121 | $30.00 |
| CRAZY CIRCUIT/CRAZY PROG | JUNE 2012 | 08106121 | $10.00 |
| CAPACITANCE DECADE BOX | JULY 2012 | 04106121 | $20.00 |
| CAPACITANCE DECADE BOX PANEL/LID | JULY 2012 | 04106122 | $20.00 |
| WIDEBAND OXYGEN CONTROLLER MK2 | JULY 2012 | 05106121 | $20.00 |
| WIDEBAND OXYGEN CONTROLLER MK2 DISPLAY BOARD | JULY 2012 | 05106122 | $10.00 |
| SOFT STARTER FOR POWER TOOLS | JULY 2012 | 10107121 | $10.00 |
| DRIVEWAY SENTRY MK2 | AUG 2012 | 03107121 | $20.00 |
| MAINS TIMER | AUG 2012 | 10108121 | $10.00 |
| CURRENT ADAPTOR FOR SCOPES AND DMMS | AUG 2012 | 04108121 | $20.00 |
| USB VIRTUAL INSTRUMENT INTERFACE | SEPT 2012 | 24109121 | $30.00 |
| USB VIRTUAL INSTRUMENT INT. FRONT PANEL | SEPT 2012 | 24109122 | $30.00 |
| BARKING DOG BLASTER | SEPT 2012 | 25108121 | $20.00 |
| COLOUR MAXIMITE | SEPT 2012 | 07109121 | $20.00 |
| SOUND EFFECTS GENERATOR | SEPT 2012 | 09109121 | $10.00 |
| NICK-OFF PROXIMITY ALARM | OCT 2012 | 03110121 | $5.00 |

| PRINTED CIRCUIT BOARD TO SUIT PROJECT: | PUBLISHED: | PCB CODE: | Price: |
|---|---|---|---|
| DCC REVERSE LOOP CONTROLLER | OCT 2012 | 09110121 | $10.00 |
| LED MUSICOLOUR | NOV 2012 | 16110121 | $25.00 |
| LED MUSICOLOUR Front & Rear Panels | NOV 2012 | 16110121 | $20 per set |
| CLASSIC-D CLASS D AMPLIFIER MODULE | NOV 2012 | 01108121 | $30.00 |
| CLASSIC-D 2 CHANNEL SPEAKER PROTECTOR | NOV 2012 | 01108122 | $10.00 |
| HIGH ENERGY ELECTRONIC IGNITION SYSTEM | DEC 2012 | 05110121 | $10.00 |
| USB POWER MONITOR | DEC 2012 | 04109121 | $10.00 |
| 1.5kW INDUCTION MOTOR SPEED CONTROLLER (NEW V2 PCB) | DEC 2012 | 10105122 | $35.00 |
| THE CHAMPION PREAMP and 7W AUDIO AMP (one PCB) | JAN 2013 | 01109121/2 | $10.00 |
| GARBAGE/RECYCLING BIN REMINDER | JAN 2013 | 19111121 | $10.00 |
| 2.5GHz DIGITAL FREQUENCY METER – MAIN BOARD | JAN 2013 | 04111121 | $35.00 |
| 2.5GHz DIGITAL FREQUENCY METER – DISPLAY BOARD | JAN 2013 | 04111122 | $15.00 |
| 2.5GHz DIGITAL FREQUENCY METER – FRONT PANEL | JAN 2013 | 04111123 | $45.00 |
| SEISMOGRAPH MK2 | FEB 2013 | 21102131 | $20.00 |
| MOBILE PHONE RING EXTENDER | FEB 2013 | 12110121 | $5.00 |
| GPS 1PPS TIMEBASE | FEB 2013 | 04103131 | $10.00 |
| LED TORCH DRIVER | MAR 2013 | 16102131 | $5.00 |
| CLASSIC DAC MAIN PCB | APR 2013 | 01102131 | **$30.00** |
| CLASSIC DAC FRONT & REAR PANEL PCBs | APR 2013 | 01102132/3 | **$25.00** |
| GPS SUB TIMEBASE | APR 2013 | 04104131 | $15.00 |
| LED LADYBIRD | APR 2013 | 08103131 | $5.00 |
| CLASSIC-D 12V to ±35V DC/DC CONVERTER | MAY 2013 | 11104131 | $15.00 |
| DO NOT DISTURB | MAY 2013 | 12104131 | $10.00 |
| LFHF-UP CONVERTER | JUN 2013 | 07106131 | $10.00 |
| 10-CHANNEL REMOTE CONTROL RECEIVER | JUN 2013 | 15106131 | $15.00 |
| IR-TO-455MHZ UHF TRANSCEIVER | JUN 2013 | 15106132 | $7.50 |
| "LUMP IN COAX" PORTABLE MIXER | JUN 2013 | 01106131 | $15.00 |
| L'IL PULSER MKII TRAIN CONTROLLER | JULY 2013 | 09107131 | $15.00 |
| L'IL PULSER MKII FRONT & REAR PANELS | JULY 2013 | 09107132/3 | $20 per set |
| REVISED 10 CHANNEL REMOTE CONTROL RECEIVER | JULY 2013 | 15106133 | $15.00 |
| INFRARED TO UHF CONVERTER | JULY 2013 | 15107131 | $5.00 |
| UHF TO INFRARED CONVERTER | JULY 2013 | 15107132 | $10.00 |
| IPOD CHARGER | AUG 2013 | 14108131 | $5.00 |
| PC BIRDIES | AUG 2013 | 08104131 | $10.00 |
| RF DETECTOR PROBE FOR DMMs | AUG 2013 | 04107131 | $10.00 |
| BATTERY LIFESAVER | SEP 2013 | 11108131 | **$4.00** |
| SPEEDO CORRECTOR | SEP 2013 | 05109131 | $10.00 |
| SIDRADIO (INTEGRATED SDR) Main PCB | OCT 2013 | 06109131 | **$30.00** |
| SIDRADIO (INTEGRATED SDR) Front & Rear Panels | OCT 2013 | 06109132/3 | $25.00/pr |
| TINY TIM AMPLIFIER (same PCB as Headphone Amp [Sept'11]) | OCT 2013 | 01309111 | **$20.00** |
| AUTO CAR HEADLIGHT CONTROLLER | OCT 2013 | 03111131 | $10.00 |
| GPS TRACKER | NOV 2013 | 05112131 | $15.00 |
| STEREO AUDIO DELAY/DSP | NOV 2013 | 01110131 | $15.00 |
| BELLBIRD | DEC 2013 | 08112131 | $10.00 |
| PORTAPAL-D MAIN BOARDS | DEC 2013 | 01111131-3 | $35.00/set |
| (for CLASSIC-D Amp board and CLASSIC-D DC/DC Converter board refer above [Nov 2012/May 2013]) | | | |
| LED PARTY PROBE (also for Hot Wire Cutter (Dec 2010)) | JAN 2014 | 16101141 | $7.50 |
| BASS EXTENDER Mk2 | JAN 2014 | 01112131 | $15.00 |
| L'IL PULSER Mk2 Revised | JAN 2014 | 09107134 | $15.00 |
| 10A 230VAC MOTOR SPEED CONTROLLER | FEB 2014 | 10102141 | **$12.50** |
| NICAD/NIMH BURP CHARGER | MAR 2014 | 14103141 | $15.00 |
| RUBIDIUM FREQ. STANDARD BREAKOUT BOARD | APR 2014 | 04105141 | $10.00 |
| USB/RS232C ADAPTOR | APR 2014 | 07103141 | $5.00 |
| MAINS FAN SPEED CONTROLLER | MAY 2014 | 10104141 | $10.00 |
| RGB LED STRIP DRIVER | MAY 2014 | 16105141 | $10.00 |
| HYBRID BENCH SUPPLY | MAY 2014 | 11104141 | $20.00 |
| 2-WAY PASSIVE LOUDSPEAKER CROSSOVER | JUN 2014 | 01205141 | $20.00 |
| TOUCHSCREEN AUDIO RECORDER | JULY 2014 | 01105141 | $12.50 |
| THRESHOLD VOLTAGE SWITCH | JULY 2014 | 99106141 | $10.00 |
| MICROMITE ASCII VIDEO TERMINAL | JULY 2014 | 24107141 | $7.50 |
| FREQUENCY COUNTER ADD-ON | JULY 2014 | 04105141a/b | $15.00 |
| VALVE SOUND SIMULATOR PCB | AUG 2014 | 01106141 | $15.00 |
| VALVE SOUND SIMULATOR FRONT PANEL (BLUE) | AUG 2014 | 01106142 | $10.00 |
| TEMPMASTER MK3 | AUG 2014 | 21108141 | $15.00 |
| 44-PIN MICROMITE | AUG 2014 | 24108141 | $5.00 |
| OPTO-THEREMIN MAIN BOARD | SEP 2014 | 23108141 | $15.00 |
| OPTO-THEREMIN PROXIMITY SENSOR BOARD | SEP 2014 | 23108142 | $5.00 |
| ACTIVE DIFFERENTIAL PROBE BOARDS | SEP 2014 | 04107141/2 | $10/SET |
| MINI-D AMPLIFIER | SEP 2014 | 01110141 | $5.00 |
| COURTESY LIGHT DELAY | OCT 2014 | 05109141 | $7.50 |
| DIRECT INJECTION (D-I) BOX | OCT 2014 | 23109141 | $5.00 |
| DIGITAL EFFECTS UNIT | OCT 2014 | 01110131 | $15.00 |
| DUAL PHANTOM POWER SUPPLY | NOV 2014 | 18112141 | $10.00 |
| REMOTE MAINS TIMER | NOV 2014 | 10112141 | $10.00 |
| REMOTE MAINS TIMER PANEL/LID (BLUE) | NOV 2014 | 19112142 | $15.00 |
| ONE-CHIP AMPLIFIER | NOV 2014 | 01109141 | $5.00 |
| TDR DONGLE | DEC 2014 | 04112141 | $5.00 |
| MULTISPARK CDI FOR PERFORMANCE VEHICLES | DEC 2014 | 05112141 | $10.00 |
| CURRAWONG STEREO VALVE AMPLIFIER MAIN PCB | DEC 2014 | 01111141 | $50.00 |
| CURRAWONG REMOTE CONTROL BOARD | DEC 2014 | 01111144 | $5.00 |
| CURRAWONG FRONT & REAR PANELS | DEC 2014 | 01111142/3 | $30.00/set. |
| CURRAWONG CLEAR ACRYLIC COVER | JAN 2015 | - | $25.00 |
| ISOLATED HIGH VOLTAGE PROBE | JAN 2015 | 04108141 | $10.00 |

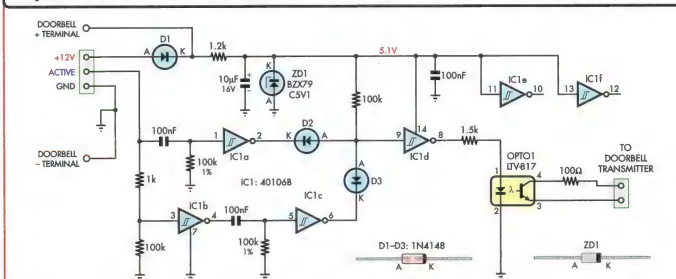
**NEW THIS MONTH:**

| | | | |
|---|---|---|---|
| **SPARK ENERGY METER MAIN BOARD** | **FEB 2015** | **05101151** | $10.00 |
| **SPARK ENERGY METER ZENER BOARD** | **FEB 2015** | **05101152** | $10.00 |
| **SPARK ENERGY METER CALIBRATOR BOARD** | **FEB 2015** | **05101153** | $5.00 |

*Prices shown in **bold** are on special: we're overstocked on these boards so YOU SAVE!*

# CIRCUIT NOTEBOOK

**Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.**




## Remote doorbell for video door-phone system

This device triggers a remote doorbell when a visitor triggers a VT-6912M Video Door Phone System (ie, a system which allows people inside the house to see and speak to a visitor before opening the door). The doorbell receiver unit can be carried around in case you are too far from the Video Door Phone System to hear its own bell.

When there is a caller at the door, the centre pin of the VT-6912M system output drops from 5V to about 0.7V for around one second. The other two pins are +12V and GND, which the circuit uses for power and this same power rail is also fed to the remote doorbell trigger unit. When the negative-going pulse is detected, the doorbell is triggered.

The circuit is based around a 40106B CMOS hex Schmitt-trigger inverter. When it detects a caller, it triggers the doorbell twice to give a longer ringing sound to better get attention. This task is performed using two "one-shot" circuit elements.

The first is based around IC1b and is triggered by the falling edge of the trigger signal. When its input pin 3 goes low, the output at pin 4 goes high and thus initially pin 5 of IC1c is also pulled high via a series-connected capacitor. As a result, output pin 6 of IC1c goes low, pulling pin 9 of IC1d low via diode D3. Output pin 8 of IC1d then goes high, turning on the LED in OPTO1 and thus simulating a press of the doorbell button.

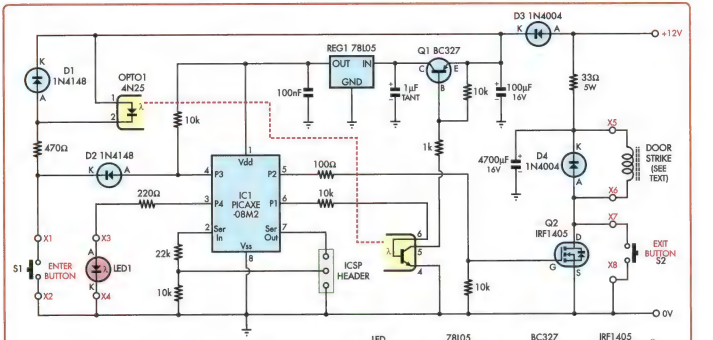
The 100nF capacitor between IC1b & IC1c is discharged by a 100kΩ resistor and so after 10ms or so, the optocoupler switches off. Later, when the output of IC1b goes low again, the circuit relies on the input clamp diodes of IC1c in combination with the 100kΩ resistor to discharge the 100nF capacitor.

Input pin 1 of IC1a is coupled to the Video Door Phone System by another 100nF capacitor which also has a 100kΩ discharge resistor. Thus, at the end of the 1s pulse from the system, when pin 1 goes high, output pin 2 of IC1a goes low for around 10ms. D2 is therefore forward-biased and so output pin 8 of IC1d goes high again, triggering the optocoupler to "press" the doorbell a second time.

While IC1 could run directly off the 12V supply from the Video Door Phone System, this would give incorrect logic high transition levels so instead the supply is regulated to about 5V using ZD1 and a 1.2kΩ current-limiting resistor. A 10µF bypass capacitor provides low AC supply impedance. The doorbell sender unit runs directly off the 12V supply, avoiding the need for its own battery.

D1 provides reverse polarity protection in case the 3-pin header is wired up incorrectly.

**Michael Azzopardi, Taylors Hill, Vic. ($45)**




## PICAXE-based electronic code lock

This electronic code lock controls an electrical door strike mechanism mounted in the door jamb. The design uses a single pushbutton to enter a 4-digit unlock code and does not require a keypad.

The unit is powered by a 12V battery pack and is independent of the mains. The circuit uses a PICAXE 08M2 microcontroller (IC1) and a 5V regulated supply that has a stand-by mode and draws virtually zero battery current when the door is locked.

The stand-by mode turns off the 4N25 optocoupler OPTO1 and BC327 transistor Q1, shutting down the 5V supply by isolating the 78L05 regulator (REG1) from the 12V battery. Pressing enter button S1 will reinstate the 5V supply by turning on OPTO1, Q1 and REG1. The microcontroller sets pin 6 high, driving pin 6 of OPTO1 and keeping the 5V supply on after the enter button is released.

Indicator LED1 is driven by the 220Ω resistor from pin 3 of IC1 and turns on each time S1 is pressed and during the unlock sequence. The prototype unit was fitted with a Jaycar SP076 illuminated pushbutton but a separate pushbutton and LED could be used if preferred. There is also an exit button (S2) and this directly controls the door strike and allows you to open the door from the inside without entering a code.

LED1 will flash four times and you should use S1 to enter one digit of the 4-digit unlock code immediately after each flash. Each digit will require between 1 and 9 button presses, delivered at a half-second on/half-second off rate. Pause for a second or more and the next digit flash will occur. The default unlock code is 1234. Change this before programming IC1; the program notes give the details.

Enter the "correct" unlock code and IC1 will flash LED1 while also turning on Q2, the IRF1405 Mosfet, unlocking the door strike for eight seconds. Enter the "wrong" unlock code and indicator LED1 will light for three seconds, leaving the door strike locked. This is followed by pin 6 on IC1 going low, in turn turning off both optocoupler OPTO1 and transistor Q1 and returning to stand-by mode.

To reduce the current taken by the door strike, a 33Ω resistor and 4700µF capacitor are used to give an initial high pick-up voltage from the charged capacitor, reducing to a lower hold-up voltage as the capacitor discharges and the resistor takes over. You must use a fail-secure door strike as this type does not consume any power in the locked state. The prototype was fitted with a Jaycar LA5077 door strike but other types may be used.

### Battery size

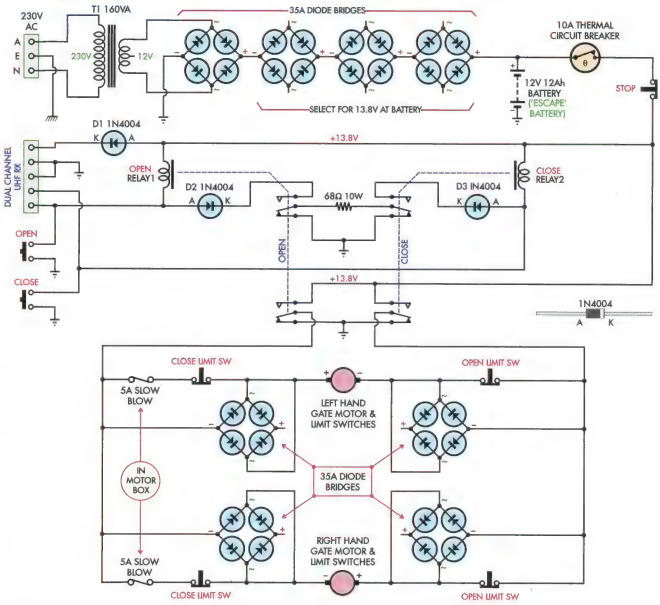
The size of battery used depends on how many times a day the door is opened and how often you want to replace the cells. The prototype is powered by two 6V lantern style batteries. The alternative is to use battery packs with eight C-size or D-size cells.

### Software

The circuit shows an ICSP header to download the software into the microcontroller and uses pin 2 as the serial input and pin 7 for the serial output signal. You will require a special PICAXE serial or USB cable to transfer the "codelock_08m2.bas" Basic program which is available from the SILICON CHIP website at www.siliconchip.com.au

While programing, press and hold S1 down to power the 5V regulator circuit.

**Ian Robertson,**
**Engadine, NSW. ($60)**




## Simple dual gate controller

This circuit was designed to provide a simpler replacement for a driver for a 4-metre wide split farm gate. The original unit was much more complex, consisting of 12 ICs, five relays and six trimpots.

The two gates are opened and closed by 60W 12V DC motors which drive via gearboxes to provide 90° of movement. Each motor also has a pair of limit switches with diodes across each limit switch, orientated so each motor can still rotate when the limit switch is operated but only away from the limit. These diodes are within bridge rectifier packages, since they can handle plenty of current and dissipation.

In this arrangement, they can be referred to as "drive back" or "drive away" diodes.

### Motor connection

The two motors are connected in inverse parallel. Thus, if 12V DC is connected across the pair of motors in one direction, the gates will open until they hit the limit switches and then stop. If the DC polarity is then reversed, the gates will close and again will stop when they hit the limit switches. Two 5A slow-blow fuses protect the motors in case something blocks the gate when closing; they are bypassed by two of the drive-back diodes so that the gate can still be opened if they blow.

The motor supply polarity is controlled by relays 1 & 2. When one relay is powered, 12V is applied across the motors, with the polarity depending on which relay. If both relays are powered, or neither, there is no voltage across the motors.

The relays are enabled using either pushbuttons S1 & S2 (mounted in a mailbox next to the gate) or via

a parallel-connected dual-channel 27MHz (FM) receiver unit. A 2-channel receiver is used in preference to the single-channel types commonly used for garage doors as this allows the gate to be opened or closed without having to first check what state it is in.

When switch S1 is pressed, 12V is connected across the coil of RELAY1 which opens the gate (if it isn't already open). The second pole of RELAY1 latches the relay on, with the 68Ω resistor reducing the coil holding current; the higher switching current is supplied initially via S1.

If S2 is then pressed, RELAY2 switches on and as there is no longer any voltage across the 68Ω resistor, RELAY1 switches off. The opposite will also occur and thus this is a bistable configuration (sometimes known as an "interlock" configuration). The 1N4004 diodes prevent the pushbuttons from activating the opposite relays via the holding resistor.

### Stop button

The stop button (fitted in the mailbox) breaks the current to the motors and relays. This could be used to prevent the gate from closing on an object stuck inside the gate. Since there is no motor current sensing to detect this condition, 20mm PVC pipe was used for the gate operating arms, so that they will buckle if the gate fails to open/close properly.

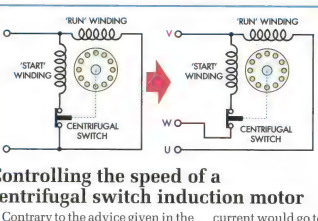
The gates are run from a 12V lead-acid battery so that they can still be used if mains power fails. This is kept on float charge with a suitable mains transformer rectified by BR1.

Additional bridge rectifiers are inserted in series with the output, connected to insert two series pairs of parallel diodes per bridge, to drop the transformer output to a suitable level for float charging (ie, around 13.8V). You may need to experiment with how many bridges are required to get your transformer output voltage to the right voltage when lightly loaded.

A whip antenna was fitted to the Elsema brand 27MHz receiver which gives a range of about 1km.

**Merv Thomas,**
**Balgal Beach, Qld. ($60)**






Ian Thompson is this month's winner of a $150 gift voucher from Rare & Forbes.

## Controlling the speed of a centrifugal switch induction motor

Contrary to the advice given in the April 2012 issue whereby the author recommended against using the Induction Motor Speed Controller to vary the speed of a single-phase induction motor with a centrifugally-switched "start" winding, it is feasible to do it. It's done by running the start winding of the motor from a separate phase of the controller as shown in the above diagram.

This means that it is necessary to gain access to the switched start winding inside the motor. By this means, it was possible to achieve broad and smooth control of the speed of an old swimming pool pump while obtaining substantial energy savings.

Initially, the pump was measured to draw 1450W at full speed (filter partially used) and by turning the speed down this could be dropped to less than 580W, whilst still achieving about 75% of the original flow rate (estimated from filter back-pressure).

On this particular pump motor, the RUN windings have a resistance of only about 2Ω but quite a high inductance, whereas the START windings are less inductive and have a resistance of about 14Ω. In normal operation, the current in the RUN winding will lag the voltage by a greater angle than that in the less-inductive START windings (perhaps by 30°) and this creates the starting torque.

With the Induction Motor Speed Controller, the START winding voltage may be advanced by 60°, to give perhaps a 90° difference between the START and RUN winding currents – an ideal result (these windings are physically 90° apart).

In practice, it was noticed that the START winding current would increase smoothly with speed, up until about 3A RMS (when the centrifugal switch would trip and the current would go to zero). Due to the high dissipation involved, it would be inadvisable to operate such a motor below the trip point for extended periods of time – however the switch typically has a very high hysteresis so once tripped, there would be no problem operating at a lower speed.

An experiment was done whereby the START winding was disconnected at quite a low speed and the motor accelerated flawlessly. This is likely because with a variable frequency drive, the motor never has to operate a very high (and low torque) slip levels – peak torque is achieved at maybe 5-10% slip.

In view of this, the switch centrifugal weights were increased (they had holes through which small bolts with Nyloc nuts could be fitted) to switch off the START windings a little earlier – although these would have to be removed to reconfigure the motor back to normal operation.

It was found that the motor would very smoothly start and run up and down through the full range of speed for a wide variety of ramp rates without a problem, the centrifugal switch opening and closing without observable effect on the motor operation (no thumps).

With respect to the installation, the Start switch (and other) connections were brought out through a sealing gland using industrial-grade armoured 4-core cable (3-phase +E), the other end of which was correctly anchored into the controller box (also through a sealed gland).

Interestingly, when the power is switched off, the motor decelerates quite abruptly; much more quickly than the normal switch off with a conventional single-phase wiring connection. (Editor's note: this is possibly due to the the action of the reverse diodes in the IGBT bridge).

**Ian Thompson,**
**Duncraig, WA.**

**Are you curious about those low-cost PC-based digital sampling oscilloscopes currently available via the web? This comparison review of the three most common units shows that they can be a cheap alternative to a full-size scope.**

By JIM ROWE

USING YOUR LAPTOP PC as the heart of a digital oscilloscope has a lot of appeal, as most laptops have a much larger screen than that in most free-standing digital oscilloscopes. But are USB scopes any good?

Typically, the vendors all claim outstanding performance, yet they are all overseas and there's no chance of being able to try their units out; you have to buy them sight unseen.

What about reviews in electronics publications? I could find only one solitary review, of the Hantek DSO-2250 USB, written by Geoff Graham, a frequent contributor to SILICON CHIP, on his website at http://geoffg.net

The Hantek scope has been available for about six years – under a variety of other brand names including Protek, Acetech, Voltcraft and Tenma. Geoff Graham didn't rate the DSO-2250 very highly and a more recent online video review really tore it to shreds. It is included in this comparison because it is well-known. The other two units are the Virtins DSO-2820R and the Link Instruments MSO-19.2 (which is actually a mixed signal scope).

Hantek and Virtins' units are made

**The Hantek DSO-2250 comes with two switchable (10x/1x) 100MHz probes, a USB cable, an 80mm software CD and a 15-page user manual. It has a maximum sampling rate of 250MSa/s and an analog bandwidth of 100MHz, although the sampling rate drops to 125MSa/s when both channels are being used (indicating that the sampling is interleaved).**

in China, while the Link MSO-19.2 seems to be made in the USA (Fairfield, New Jersey). All three come with drivers and software for PCs running Windows.

## Hantek DSO-2250

The Hantek unit is housed in a moulded plastic box measuring 190 x 100 x 33mm and weighing 304g. It comes with two switchable (10x/1x) 100MHz probes, a USB cable to be hooked up to two USB ports on your PC, an 80mm software CD and a 15-page A5-size user manual which mainly covers software installation.

Hantek claims that the DSO-2250 has a maximum sampling rate of 250MSa/s and an analog bandwidth of 100MHz. However, that only applies when a single channel is being used. With both channels in use, the sampling rate drops to 125MSa/s – so the sampling must be interleaved.

Since the effective analog bandwidth is usually defined as the maximum sampling rate divided by at least 2.5, this means that when both channels are used the effective bandwidth for each channel must drop to 50MHz. This is still quite respectable, although it's not necessarily achieved by the DSO-2250's analog input channels.

When it comes to the size of the internal buffer memory, Hantek specifies a range of 10K – 512K sample points. This upper limit sounds good but after playing with their software for quite a while I still couldn't figure out (a) whether these figures apply to one or both channels or (b) how to increase the buffer size from 10K anyway. This figure seems to be fixed, although it does seem to apply to each channel.

For triggering, the DSO-2250 software lets you choose either one of the two main input channels, both alternately, or the external trigger input (either directly or via a 10:1 attenuator). It also provides a choice of Auto/Normal/Single shot trigger modes, edge triggering (± slope), automatic 50% level triggering and adjustable triggering level over a range of ±4 full vertical divisions. Plus you can also select an HF rejection filter.

There's quite an impressive range of waveform voltage and time/frequency measurements: Vpp, Vmax, Vmin, Vmean, Vrms, Vamp and ±overshoot; plus period, frequency, ±pulse width and rise/fall times. You can also average between 1-128 traces for noise reduction, select either Step, Linear or Sin(x)/x interpolation and even select a virtual display persistence of either zero or within the range of 100ms – 10s.

In addition, the DSO-2250 provides an FFT (Fast Fourier transform) based Spectrum Analyser function, with five selectable bin sizes (256, 512, 1024, 2048 or 4096) and a choice of Rectangular, Hanning, Hamming or Blackman window functions.

Hantek doesn't specify the current drawn by the DSO-2250 from the PC's USB port but the fact that it is supplied with a USB cable fitted with two Type-A plugs at the PC end suggests that its current drain is fairly hefty. We measured it at between 560mA and 580mA. That explains the second Type-A plug, to share the load between two of the PC's USB ports.

## Virtins DSO-2820R

We reviewed the Virtins Multi-Instrument virtual instrument software MI3.2 in the September 2012 issue of SILICON CHIP. This software was capable of turning a PC with a decent-quality sound card into a 2-channel audio scope combined with an FFT spectrum analyser, plus a 2-channel audio signal/function generator.

In the same issue, we described a Virtual Instrument Audio Test Interface and you can see a 2-page preview at

**Virtins' DSO-2820R is a 2-channel USB DSO and FFT spectrum analyser, with a maximum sample rate of 200MSa/s (one channel) or 100MSa/s (two channels) and a claimed analog bandwidth of 80MHz. It's housed in an extruded aluminium case and comes with a pair of switchable (10x/1x) 100MHz test probes, a USB cable and a CD with Virtins MI software, the Windows drivers and two manuals in PDF format.**

**The Link Instruments MSO-19.2 is the smallest of the three units but still packs in a single-channel DSO with a maximum sampling rate of 200MSa/s and a claimed analog bandwidth of 60MHz. Also included is an 8-bit digital logic analyser that can also sample at up to 200MSa/s (synchronised with the DSO) with decoders for SPI and $I^2C$ serial digital signals, a 100MSa/s pattern generator or digital word generator, and an FFT spectrum analyser covering from DC to 100MHz. And it also has the makings of a pulse-type time domain reflectometer or TDR!**

www.siliconchip.com.au/Issue/2012/September/USB+Test+Instrument+Interface+For+PCs

The DSO-2820R is one of a number of PC-based DSOs from Virtins now, all supplied with the Multi-Instrument software – now revised as MI3.4.

The DSO-2820R is again a 2-channel USB DSO and FFT spectrum analyser, with a maximum sample rate of 200MSa/s (one channel) or 100MSa/s (two channels) and a claimed analog bandwidth of 80MHz. (There's also the lower cost DSO-2810R [US$200] with a maximum sample rate of 100MSa/s, and the larger and more expensive DSO-2820E [US$370] which combines the 2820R DSO and spectrum analyser with a 10-bit 200MSa/s DC-60MHz arbitrary waveform/signal generator.)

Smaller than the Hantek unit, the Virtins DSO-2820R is housed in an extruded aluminium case measuring 115 x 70 x 25mm and has an overall weight of 150g. It comes with a pair of switchable (10x/1x) 100MHz test probes, a USB cable to hook it up to one USB port on your PC and a 120mm CD with a bundled copy of Virtins MI software, plus the Windows drivers and two manuals in PDF form – ie, an 80-page hardware manual and a 296-page MI software manual (some of which is not applicable with the DSO-2820R).

Virtins claims a maximum sampling rate of 200MSa/s and an analog bandwidth of 80MHz for the DSO-2820R. You will find that the 200MSa/s sam-

pling rate only applies when a single channel is being used. With both channels in use, the figure drops to 100MSa/s – again, the sampling must be interleaved. The effective analog bandwidth would also drop to 40MHz.

The size of the 2820R's internal frame buffer memory is given as 40,000 bytes, which equates to 40,000 8-bit samples using a single channel or 20,000 8-bit samples per channel when using both channels. This is for normal real-time 8-bit sampling in frame mode. However, Virtins claims that the 2820R and its other second generation DSOs offer additional features, such as hardware DSP-based bit-resolution-enhancement (BRE) and an adaptive anti-aliasing filter.

The BRE feature is only available for sampling rates below 100MSa/s but when it is enabled the effective sampling resolution of the 2820R increases by 1/2 a bit for each halving in sampling frequency. So for a sampling rate of 25MSa/s, BRE gives an effective bit resolution of 9 bits, rising to 10 bits at sampling rates below 6.25MSa/s, 11 bits at rates below 1.563MSa/s and so on. In fact, the effective bit resolution can be raised to a full 16 bits for sampling rates of 1.526kSa/s and below.

In other words, BRE provides a way of trading sampling rate for effective sampling bit resolution – allowing you to examine and measure low-frequency signals with higher resolution.

Virtins MI software also allows for equivalent time sampling and Streaming/Record mode sampling. The triggering flexibility is also quite good, with Auto/Normal/Single shot or Slow trigger modes, edge triggering (± slope), adjustable triggering level and trigger delay adjustable anywhere between the start (-100%) and finish (+100%) of the record length (normally the delay is set to 0%, or the centre of the record).

You can also choose between either of the two main input channels as the trigger source when they're both being used. There's also the ability to select from 13 different trigger signal filtering options including NIL (all pass), HFR (high frequency reject), NR0-NR4 for noise rejection, HN0-HN4 for HF rejection plus noise rejection, and HNX for user-configurable filtering.

Voltage and time/frequency measurements (Vmax, Vmin, Vmean and Vrms) are displayed automatically at the top of the DSO display window, while Vrms, frequency, duty cycle,

## FIG.1: A COMPARISON CHART OF THREE LOW COST PC-BASED / USB POWERED DSO & MSO DEVICES

| BRAND, MODEL & COUNTRY OF ORIGIN | COST IN US DOLLARS, (EXCLUDING FREIGHT) | NUMBER OF INPUT, OUTPUT CHANNELS | RESOLUTION, MAXIMUM SAMPLING RATE | CLAIMED ANALOG BANDWIDTH | FRAME BUFFER SIZE | PHYSICAL CASE SIZE, MATERIAL & WEIGHT | PROBES & CABLES SUPPLIED | WINDOWS DRIVER & SOFTWARE SUPPLIED? | HARDWARE & SOFTWARE MANUALS SUPPLIED? | TRIGGERING FACILITIES | CURRENT DRAIN FROM PC's USB PORT(S) | MAIN FEATURES | ADDITIONAL FUNCTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HANTEK DSO-2250<br><br>CHINA (QingDao Hantek Electronics) | $220.00 | 2x Analog Inputs (1M//25pF) one External Trigger Input, 1 x Digital (Probe Comp) Output | 8 bits/channel, 250MSa/s (1 Channel) 125MSa/s (2 Channels) | 100MHz (1 Ch), 2 x 60MHz (2 Ch) | 10K points per channel | 190x100x33mm, Plastic (ABS), 304g | 2 x 1M (x1)/ 10M (x10) Input probes, 1 x USB cable (2 Type A plugs, 1 x Type B plug) | YES (80mm CD) | 15-page A5 User Manual only | SOURCES: Ch1,Ch2, Alt, External, Ext/10 MODES: Auto, Normal, Single Edge, ±Slope, HF reject TRIG LEVEL: 50% or full scale adjustable | 560-580mA running or stopped (2 USB ports required) | MEASUREMENTS: Vpp, Vmax, Vmin, Vmean, Vrms, Vamp, ± overshoot, Period, Frequency, ± pulse width, rise/fall time etc. Averaging (1 –128 traces) Interpolation (Step, Linear, sin(x)/x) Persistence (Min, 100ms – 10s) | FFT/SPECTRUM ANALYSIS: Five bin sizes (256 – 4096), Four Window Functions (Rectangular, Hanning, Hamming, Blackman) |
| VIRTINS VT DSO-2820R<br><br>CHINA VIA SINGAPORE (Virtins Technology) | $249.00 | 2x Analog Inputs (1M//15pF), 1 x Digital (Probe Comp) Output | 8–16 bits/ch, 200MSa/s (1Channel) 100MSa/s (2 Channels) - Frame Mode, 2GSa/s RIS Mode* Sampling | 2 x 80MHz | In Frame Mode, 20K (16b) or 40K (8b) Samples per channel.<br><br>In Streaming Mode, Limited only by PC memory or Hard Disk | 115x70x25mm, metal (Aluminium), 150g | 2 x 1M/10M (x1/x10) Input probes, 1 x USB cable (Type A plug to Type B plug) | YES: Virtins Multi-Instrument 3.3 (120mm CD) | 80-page A4 Hardware Manual Plus 296-page Mi 3.3 Software Manual (both in PDF form on CD) | SOURCES: Ch1, Ch2, Alt MODES: Auto, Normal, Single, Slow Edge, ± Slope, HF reject, noise rej TRIG LEVEL: Full scale adj, Adj Pre/Post Dig Triggering | 322mA running, 250mA stopped | MEASUREMENTS: Vmax, Vmin, Vmean, Vrms, dBV, dBu, dB, dB(A/B/C) Frequency, RPM, duty cycle etc (Many of these via the 'DMM' display.) | FFT/SPECTRUM ANALYSIS: Nine bin sizes (128 – 32768), 50 Window Functions<br><br>CALIBRATION SIGNAL GENERATOR: Square wave or MLS, Frequency 25MHz/N where N = 1 – 25000. |
| LINK Instruments MSO-19<br><br>USA (Link Instruments, Fairfield, NJ) | $249.00 | 1x Analog Input (1M//15pF), 8 x Digital Inputs/Outputs (logic Analyser, Pattern Gen), 1 x Trigger Output | 8 bits (DSO), 200MSa/s Single Shot, 2GSa/s RIS Mode* Sampling | 60MHz | 1000 points per channel (DSO, Logic Analyser) | 92x61x20mm, plastic (ABS), 74g | 1 x 1M/10M (x1/x10) Input Probe, harness with 15x Digital I/O leads, 9 x nano clips, USB cable (Type A plug to Mini Type B plug) | YES (120mm CD) | 4-page A5 Install Guide plus 100-page Software Manual in PDF form on CD | SOURCES: DSO or any combn of Logic Analyser inputs MODES: Auto, Normal, Single Edge, ±Slope, <pulse width> TRIG LEVEL: full scale adjust, Pre/Post trig for Logic Analyser | 300mA running, 275mA stopped | MEASUREMENTS: Vpp, Vrms, Vmin, Vmean, Vmedian, Vrms, VcursorA, VcursorB Period, Frequency, ±pulse width, rise/fall time etc.<br><br>Logic Analyser, SPI and I2C analysis | FFT/SPECTRUM ANALYSIS: 1000 points/channel Seven Window Functions<br><br>8-bit LOGIC ANALYSER: 100MHz bandwidth<br><br>PATTERN GENERATOR: Maximum 1023 points, Rate 10kSa – 100MSa/s<br><br>SPI & I2C DECODERS |

*RIS mode is 'Random Interleave Sampling', one variant of Equivalent Time Sampling or 'ETS' (used to achieve higher effective sampling rates, but for repetitive signals only)

## x1 Probe Bandwidth

The blue curves in Fig.2 show the much poorer bandwidth of all three USB-DSO devices when their input probes were switched into their x1 position. This is quite typical – even though probe and scope manufacturers are usually rather coy about this.

The reason for the reduced bandwidth of the probes in their x1 position is that their frequency compensation is designed to optimise performance in the x10 position, where the input signal is divided by 10 before passing through the distributed capacitance, resistance and inductance of the output cable.

Since the input divider and compensation are effectively shorted out in the x1 position, the signals end up being attenuated by the output cable before they reach the input of the scope.

So if you want to achieve the full bandwidth of any scope for measuring small signals, it's better to use a direct connection to the scope input – not a x10/x1 probe switched to its x1 position.

dBV, dBu, dB and dB(A/B/C filtering) can be displayed in a separate DMM window.

There doesn't appear to be any provision for averaging, while the Chart options seem to provide a choice of Line, Scatter, Column, Bar and Step so there is no option for sin(x)/x interpolation. However, you can select a virtual display persistence of either Zero, Phosphorescent, Rainbow or Equivalent Time Sampling (with the ability to set the number of frames). You can also set the trace line width from 1-10 pixels.

In addition, the DSO-2820R again provides an FFT (Fast Fourier Transform) based Spectrum Analyser function, with nine selectable bin sizes (128-32,768) and 50 different window functions to suit many different applications. As well as Rectangle, Triangle, Hamming, Hanning, Blackman, Exact Blackman, Blackman-Harris and Blackman-Nuttal, Flat Top, Welch, Riemann, Parzen and Bohman, there are 14 different Kaiser windows, three Poisson, three Hanning-Poisson, three Cauchy, three Tukey, four Cosine and three Gaussian windows.

Virtins quote the DSO-2820R's maximum power consumption as 1.5W. We measured the total current drain at 250mA when the DSO and FFT were stopped and 322mA when they were running. In other words, just over half the drain of the DSO-2250 and well within the capabilities of a single standard USB 2.0 host port.

### Link Instruments MSO-19.2

This is the smallest of the three units and is housed in a moulded plastic case measuring 92 x 61 x 20mm and weighing a mere 74g. Yet Link Instruments has managed to pack in a single-channel DSO with a maximum sampling rate of 200MSa/s and a claimed analog bandwidth of 60MHz, an 8-bit digital logic analyser that can also sample at up to 200MSa/s (synchronised with the DSO) with decoders for SPI and $I^2C$ serial digital signals, a 100MSa/s pattern generator or digital word generator, and an FFT spectrum analyser covering from DC to 100MHz. And it also has the makings of a pulse-type time domain reflectometer or TDR!

So as well as being very small and light, it's a versatile mixed signal package of PC-based test instruments. Small wonder Link Instruments can boast that the MSO-19 was chosen by NASA as the only oscilloscope to be provided on the International Space Station.

It comes with a single passive switchable (10x/1x) 100MHz test probe but there's also a plug-in 15-wire harness for the digital logic analyser inputs and pattern generator outputs, together with nine nanoclips for attaching the digital leads to a device under test (DUT).

There is also the USB cable, a 4-page A5 installation guide, a 120mm CD with the companion drivers and software, plus a 100-page software manual PDF.

Although the MSO-19.2 has a maximum real-time sampling rate of 200MSa/s, it also has provision for RIS (Random Interleaved Sampling), a type of Equivalent Time Sampling (ETS), at rates of either 1GSa/s or 2GSa/s. The interpolation seems to be fixed at linear though, for both real time and RIS sampling.

The size of the MSO-19.2's internal buffer memory appears to be 2KB, with 1023 bytes allocated to the DSO for storage of 1000 sample points and the other 1023 bytes used for storing the logic analyser and pattern generator data. When either of these buffers become full, their contents are transferred to the PC via the USB cable.

There is a choice of Auto/Normal/Single shot trigger modes, edge triggering (± slope), adjustable triggering level over a range of ±4 full vertical divisions with a resolution of 12.5mV, and pulse width triggering. There's also an Autosetup mode.

Triggering can be from the DSO input channel or any of the eight logic analyser digital inputs. The chosen triggering signal also becomes available via the second BNC connector on the front of the case, although this connector can also be used as an output for the probe compensation signal, a white noise signal, the TDR output pulses or a low-frequency function generator signal.

The measurements comprise Vmax, Vmin, Vpp, Vmean, Vmedian and Vrms, frequency, period, ± pulse width and rise/fall times. In addition, you can activate two voltage cursors and two time cursors, to allow other measurements.

The MSO-19.2's FFT based spectrum analyser function seems to offer a fixed number of bins but a choice of seven window functions: Rectangular, Tapered Rectangular, Triangular, Hamming, Hanning, Flat-Top or Blackman-Harris. There's also a choice of display types: Magnitude, Power Spectrum, Power Density, Real or Imaginary. There's also the ability to produce and display an average over 10, 20, 50 or 100 captures.

Total current drain of the sample unit proved to be about 275mA when the DSO and logic analyser were stopped, and about 300mA when they were running; well within the capabilities of a PC's USB2.0 port.

### Bench tests

Our first tests on each of the devices were to check out their actual analog bandwidths. We did this by installing each one's driver and software on a Compaq CQ61 laptop running Windows 7 Home Premium (32-bit), and then checking its HF response when

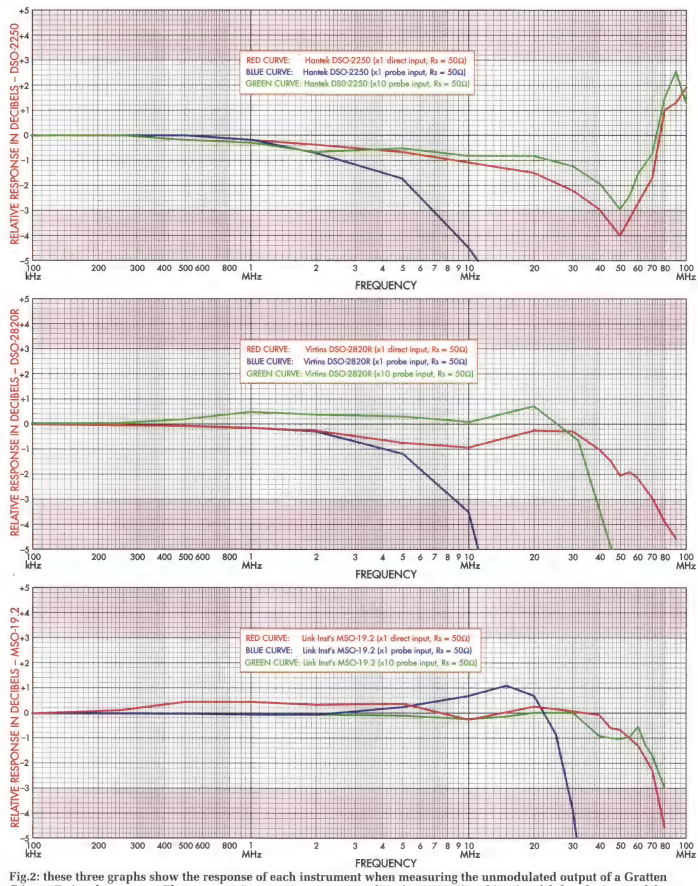



**Fig.2: these three graphs show the response of each instrument when measuring the unmodulated output of a Gratten GA1484B signal generator. The generator's output was set to +13dBm (1.0V RMS) and its signal fed to the input of the device being tested via a 50Ω cable, terminated with a 50Ω load. Three different tests were done: (1) with the generator signal fed directly into the DSO channel input; (2) with the signal fed via the matching test probe, set to the x10 position and with its compensation optimised; and (3) with the signal via the same test probe set to the x1 position.**

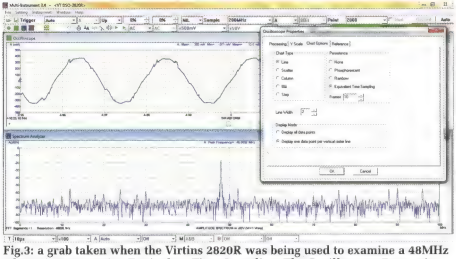


**Fig.3: a grab taken when the Virtins 2820R was being used to examine a 48MHz 0dBm sinewave using Equivalent Time Sampling. The Oscilloscope Properties dialog is open at upper right, with the waveform visible to its left and the FFT plot below.**

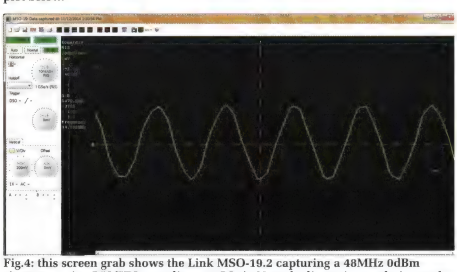


**Fig.4: this screen grab shows the Link MSO-19.2 capturing a 48MHz 0dBm sinewave using RIS/ETS sampling at 1GSa/s. Note the linear interpolation and the frequency measurement error.**

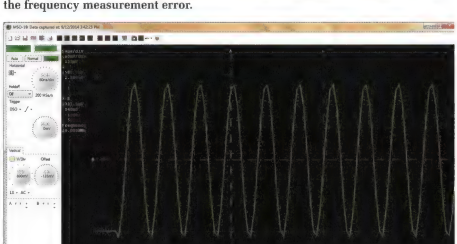


**Fig.5: the Link MSO-19.2 capturing a 20MHz +13dBm sinewave at 200MSa/s. The linear interpolation is again quite evident.**

measuring the unmodulated output of a Gratten GA1484B signal generator.

The generator's output was set to +13dBm (= 1.0Vrms) and the output signal taken to the input of the device being tested via a 50Ω cable, terminated with a 50Ω load at the device end to minimise reflections and standing waves. Three different tests were done: (1) with the generator signal fed directly into the DSO channel input; (2) then via the matching test probe, set to the x10 position and with its compensation optimised; and (3) finally, via the same test probe to the x1 position.

The results of these tests are shown graphically in Fig.2. In each case, the curve for the first (direct) input test is shown in red, that for the compensated x10 test probe test is shown in green and that for the x1 test probe test is shown in dark blue.

You'll see that the basic analog bandwidth of the Virtins DSO-2820R is within +0/-1dB up to 40MHz and falls to -3dB at very close to 70MHz; Similarly, the Link MSO-19.2 is within +0.5/-0.5dB up to 44MHz and falls to -3dB at about 74MHz. In this respect, they're both noticeably better than the Hantek DSO-2250 which falls to the -1dB point at about 8MHz and falls to -3dB at close to 40MHz. Then after falling to -4dB at 50MHz, it rises again to reach +1.9dB at 100MHz.

We can probably attribute that upward rise in the DSO-2250's red curve to aliasing artefacts, so this part of the curve is best ignored.

If we look at the green compensated x10 probe curves, the results are a little more equivocal. Even the response of the Hantek DSO-2250 doesn't fall to -1dB until 24MHz and extends out to 40MHz before it drops to -3dB. In other words, the compensated x10 probe actually lifts the performance of the DSO-2250.

On the other hand, the Virtins DSO-2820R is now within +0.7/-1.0dB only up to 34MHz, and falls to -3dB at about 38MHz – so the compensated x10 probe has lowered its performance a little.

The Link MSO-19.2's compensated x10 probe has again improved its performance slightly, albeit with a small dip between 40-50MHz and a small peak at 60MHz. But its -3dB point has risen to just on 80MHz.

The three blue curves show the x1 probe responses. These all show a significant drop in bandwidth compared with the direct input bandwidth of each device. This is to be expected as it's a fairly well known limitation of the x1 position of just about all switched passive probes.

But the really surprising thing when

you compare the three blue curves in Fig.2 is that the bandwidth of the MSO-19.2 with its probe in the x1 position is much better than the other two. It rises to a broad +1dB peak at 15MHz and only falls to -3dB at about 28MHz. This improved performance of the MSO-19.2's probe in the x1 position suggests either that it's of a higher quality or that Link has built some compensation into its software.

## RIS/ETS sampling

As already noted, both the DSO-2820R and the MSO-19.2 offer the ability to perform RIS/ETS sampling as well as real-time sampling, to allow better definition of higher-frequency repetitive signals. We tried out the ETS functions of both devices but we were not overly impressed with either of them.

On the DSO-2820R, we initially had a problem even getting the MI3.3 software to allow us to turn on the ETS option in the Oscilloscope Chart Options dialog – it seemed to be permanently greyed out and unavailable. It was only after sending a help email to Virtins that we received a reply explaining that the trick was to set the Trigger mode to Normal, the Trigger Frequency Rejection to NIL and the Trigger Delay to zero or less than zero.

We were advised that this is indicated on page 105 of the MI3.3 software manual and when we looked on that page there it was – not in the text though, just buried in a screen grab.

When we did get the ETS function working, we were able to capture a few waveforms that appeared to be sampled at a higher sampling rate. However there was no indication on the screen of the effective sampling rate – just the actual real-time sampling rate in the usual position near the top of the screen.

In any case, the waveform being displayed seemed to be infected with travelling glitches, like those visible in the screen grab of Fig.3 (which shows a sinewave at 48MHz). This can also be seen from the FFT display of the same waveform below it where quite a few spurs were also visible – although most of them remained below about -55dBV.

At first we wondered if these glitches and spurs were due to speed limitations in the processor of the laptop being used, which only has an Intel dual-core Celeron CPU running at 1.8GHz. So we tried installing the

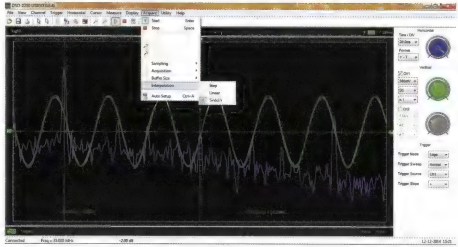


**Fig.6: here's a grab of the Hantek DSO-2250 capturing a 35MHz +10dBm sine-wave signal, with the acquisition menu showing that sin(x)/x interpolation has been selected. Note the smoother sine waveform (green), plus the superimposed FFT in deep purple.**

MI3.3 software and Virtins driver on a somewhat faster Asus BP6320 desktop with an Intel Core i7-3770 CPU running at 3.4GHz, with Windows 7 Pro (64-bit) and a 250GB SSD.

The results were almost identical, so the glitches and spurs must be due to something else.

When we tried out the RIS/ETS function on the MSO-19.2, the results were a little more promising. The MSO-19.2's software does show you the effective sampling rate in this mode, just below the horizontal speed knob at upper left on the screen. And there were no glitches as such on the waveform display – just moving linear interpolation vector lines and their junctions, as you can see in the screen grab of Fig.4.

As the displays using real-time sampling are much the same (see Fig.5), we are inclined to think that the effect is due to the lack of sin(x)/x sample interpolation in the MSO-19.2's display processing. Virtins MI3.3 and MI3.4 don't seem to offer sin(x)/x interpolation either, so that may be part of the explanation for those glitches.

## FFT/spectrum analyser functions

When we checked the FFT/spectrum analyser functions on each of the three DSOs, there were strengths and weaknesses in each one.

For example, Hantek's DSO-2250 offers five bin sizes (from 256-4096) and four window functions, plus trace averaging and variable persistence. Yet the spectrum display can only be shown superimposed on the waveform display and seems to be fixed in colour to a rather dark purple which is hard to read (see Fig.6).

There's also a weird problem in the FFT settings dialog box, where the first and second harmonics are always the same in both frequency and value (Fig.7).

With the Link MSO-19.2 software, there seems to be only a fixed number of FFT bins ("1000", presumably 1024) but a choice of any of seven window functions: Rectangular (Dirichlet), Tapered Rectangle (Tukey), Triangular (Bartlett), Hamming, Hanning, Flat-Top and Blackman-Harris. The spectrum can also be scaled in Magnitude (mV), in Power Spectrum (dBm), in Power Density or in its Real and Imaginary components. Multiple FFTs can also be averaged to give a clearer spectrum display – see Fig.8.

The Virtins DSO-2820R + MI soft-

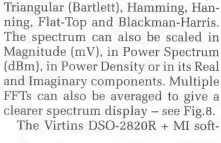


**Fig.7: this is the FFT Setting dialog box in Hantek's software for the DSO-2250, showing how the window function and number of bins can be selected. Note the curious duplication of the first and second harmonics information.**

## Nyquist-Shannon Sampling Theorem

You'll find the name "Nyquist" cropping up frequently when you're reading about digital sampling, DSOs, ADCs and DACs – either by itself or together with the name "Shannon". That's because Harry Nyquist and Claude Shannon were two of the main researchers and theorists working in the field of information and sampling theory early last century.

The sampling theorem usually named after them essentially defines the maximum signal frequency **Fmax** that can be conveyed by a digital sampling system working at a sampling frequency **Fs**:

$$Fmax < Fs/2$$

By the way Fs is often called the Nyquist Rate, while Fs/2 is usually called the Nyquist Frequency.

This looks simple enough but a couple of aspects need to be kept in mind when you're dealing with sampling. First, Fmax refers to the highest frequency COMPONENT in the signal being sampled. For example, a clean 99MHz sinewave signal can be conveyed at a sampling rate of 200MSa/s and reconstructed faithfully at the output – at least in theory. But the same can't be done with a nominal 99MHz signal having a more complex waveform, because this will have harmonics and other components at frequencies well above 99MHz.

Remember – Fmax applies to ALL components in the signal, not just the fundamental.

The other thing to remember is that the Nyquist-Shannon theorem assumes that all samples are equally spaced in time. In other words, that Fs is fixed and constant. This often doesn't happen in the real world, where sampling clock signals generally have at least a small amount of jitter.

The Nyquist-Shannon theorem tells you the effective analog bandwidth of a digital scope by defining Fmax as below Fs/2. So with a DSO sampling at 200MSa/s, Fmax will be just below 100MHz. But remember that this limit is (a) theoretical and assumes no clock jitter and (b) applies to all frequency components in the signal to be measured.

Digital scope makers often play safe by quoting a figure of Fs/2.5 for the effective analog bandwidth of their instrument. But even this figure is really only relevant for practical measurement of sinewave signals. When you want to examine square waves or other signals with a high harmonic content, it's best to assume that the effective bandwidth is nearer Fs/10.

For example, you really need a digital scope sampling at 1GSa/s to examine complex signals at frequencies up to 100MHz. And conversely, a USB scope sampling at 200MSa/s has an effective analog bandwidth of around 20MHz for complex signals.

ware doesn't have any of the problems of the DSO-2250 mentioned above. It also has a larger choice of nine bin sizes (from 128 - 32,768), plus those 50 different window functions. The DSO and spectrum displays can also be shown either separately on screen or both together (one above the other). But there does seem to be a lot of aliasing spurs on the spectrum display, as shown in Fig.9.

### Extra functions

In addition to its DSO and FFT/Signal Analyser functions, the DSO-2820R provides a signal generator function of sorts. This makes use of the same internal circuit used to generate the 1kHz square-wave probe compensation adjust signal, available via the small terminal lug on the DSO-2820R's front panel.

The signal generator is limited to providing a digital or single bit output – essentially either a square wave or a maximal length sequence (MLS), and with a fixed amplitude of roughly 3.3Vp-p. However, it can be programmed in terms of frequency, via the DAC Device Setting dialog (accessed via the Setting -> DAC Device menu options).

This dialog allows you to set the generator to any frequency defined by the expression 25MHz/N, where N is any integer between 1 and 25,000. You don't have to work the divisor out for yourself though; you simply type in the frequency you want and the MI software gives you the closest frequency it can produce.

Clearly it can't provide any frequency below 1kHz, because this is the lowest frequency available (and just happens to be the default frequency used for adjusting probe compensation). But it is capable of providing 25,000 discrete frequencies, with good resolution down at the low end but gradually becoming poorer as you move up.

At 10kHz the resolution is only about 4Hz for example, while at 100kHz it has risen to about 400Hz. Still, this could be useful in some applications.

The Link MSO-19.2 also provides a number of extras, including the 8-bit logic analyser with 100MHz bandwidth, SPI and $I^2C$ decoders, an 8-bit pattern generator and a pulse-type TDR. The latter again seems to be based on the internal probe compensation pulse generator, as its output emerges from the same BNC output connector.

So all you need for pulse-type TDR measurements is a short BNC-BNC cable, a BNC T-adaptor and possibly a coaxial series adaptor or two (for when you want to check cables fitted with connectors other than BNC).

Note that when used as a TDR, the MSO-19.2 by itself can only be used to check 50Ω cables. On the plus side, it can convert delay times into distances along the cable providing you select the cable VOP (velocity of propagation).

### TDR comparisons

While we're on the subject of TDR, we did try out each of the three scopes with our own Step-type TDR Dongle as described in the December 2014 issue of SILICON CHIP. The results were interesting.

The DSO2250 could display the Step-type TDR waveforms quite nicely but proved to be somewhat counter-intuitive when it came to using its vertical cursors to measure the delay time between the start of the step and any reflection of interest. Since there is no real user manual and only a very sketchy online help file, we had to work out how to do it for ourselves. But once we had done so it did give quite useful results.

With the Virtins DSO-2820R, there

## Useful Links

www.hantek.com/en/
www.hantek.in/en/
http://geoffg.net
www.virtins.com
www.multi-instrument.com
www.linkinstruments.com
http://shop1.usbdso.com

is no facility for moving the trigger point in from the lefthand side of the display (ie, no pre-trigger display). This makes it difficult to be sure that you are measuring from the start of the TDR step. That aside, it proved reasonably easy to make most TDR timing measurements.

Although the MSO-19.2 does have its own pulse TDR generator built in, we found that it too would work with our Step TDR Dongle. Not only that, it would still convert reflection delay times into distances along the cable – providing you set the software into its TDR mode and select the appropriate VOP.

However, the MSO-19.2 input has a maximum full-scale vertical range of 4V (±2V), so it can't display the full step waveform output of the TDR Dongle when there's either no cable connected or the cable has an open-circuit somewhere. The trace simply flies up to the top of the display and stays there.

### And the winner is?

That's not easy to answer because all three devices have their strengths and weaknesses. If you mainly want a 2-channel scope with the highest possible bandwidth, the Virtins DSO-2820R would probably be the winner.

If you want the highest possible bandwidth but only need a single scope channel, the Link MSO-19.2 would be your best bet.

Things get a bit more confusing if you're really looking for the most versatile FFT/Spectrum Analyser function. Here you'd probably want to go with the Virtins DSO-2820R and its MI software with nine bin sizes and choice of 50 window functions. But the Hantek and Link devices and their software are really not all that far behind when it comes to many practical applications.

Finally, if you only need a single channel scope but would also like the added features of an 8-bit 200MSa/s logic analyser, a 1023x8-bit 100MSa/s pattern generator and a pulse-type TDR, then go for the Link Instruments MSO-19.2. SC

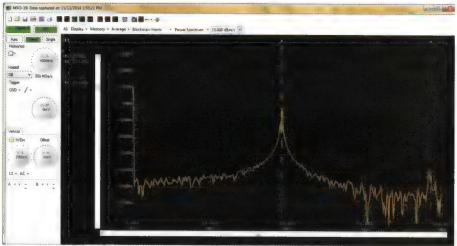


Fig.8: the FFT display when the Link MSO-19.2 was being used to examine a 48MHz 0dBm sinewave signal with sampling at 200MSa/s (real time sampling).

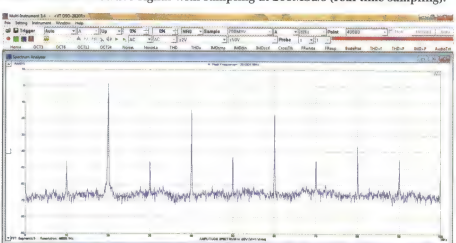


Fig.9: the FFT spectrum displayed by the Virtins 2820R (with the MI3.4 software) when checking a 20MHz +13dBm sinewave signal. Note the relatively high harmonic peaks at 40, 60 and 80MHz (possibly due to front-end overload) and the spurs at 10MHz, 30MHz and so on – probably caused by aliasing.

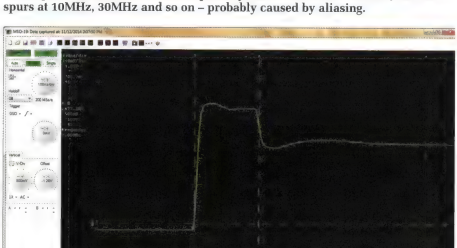


Fig.10: here the MSO-19.2 was being used with our Step-TDR Dongle, to examine an 18m-long cable terminated in 25 ohms. In its TDR mode, the MSO-19.2 can even work out the cable distance corresponding to a reflection delay time.

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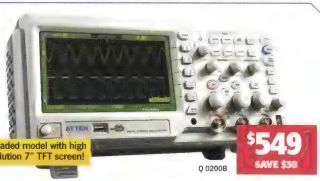

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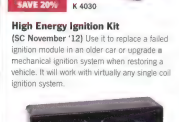
The Currawong amplifier is a tried and tested valve amplifier circuit which has been adapted to components which are readily available. Each channel uses two 12AX7 twin triodes for the preamp and phase splitter stages and two 6L6 beam power tetrodes in the class-AB ultra-linear output stage. It performs very well, with low distortion and noise.

**Features:**

- Two pairs of 6L6 beam power tetrodes
- Two pairs of 12AX7 twin triodes
- 2x10W RMS power output into 8 Ohm loads
- Remote volume control

**Features both valve technology and solid state parts for a modern twist.**

**Supplied with:** This kit includes all valves, PCB, componentry, acrylic board cover, transformers & panels. It **does not** include parts to build the enclosure. We suggest building your own to suit your own style.



$42 SAVE 20%

K 4030

## High Energy Ignition Kit

**(SC November '12)** Use it to replace a failed ignition module in an older car or upgrade a mechanical ignition system when restoring a vehicle. It will work with virtually any single coil ignition system.

Great for D-I-Y & trades.

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K 6043

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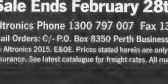
## Threshold Voltage Switch Kit

**(SC Jul '14)** A versatile design which switches a relay when an input crosses a preset threshold. 5, 12, 24V power input. Includes S 4190D 5A relay. Trigge can be high or low.



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Great for working with sensors

K 2572

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## USB Datalogger Kit

**(SC Dec '10 - Mar '11)** Based on a PIC micro, this project can log data to an SD card. It can read from many types of digital & analog sensors. A real-time clock time-stamps the data. PC host program allows you to configure sensors, change settings and charge the battery via USB (2 x AAA, not included).

K 2558

$72 SAVE 15%

## Capacitor Leakage Meter Kit

**(SC Dec '09).** Performs leakage current testing on almost any type of capacitor. A valuable piece of test equipment for servicing. Seven test voltages from 10-100V. Leakage current 10mA-100nA. Requires 6 x AA batteries.

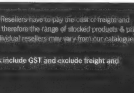
Designed by Altronics!

$119 NEW KIT!

K 7520

## Resistance & Capacitance Decade Box Kit

**(SC Aug '14)** A decade box is a really handy device for trying capacitor and resistor values in-circuit before you select the final value to solder down. This box offers a 1Ω to 999.999Ω resistance range and 100pF to 9.99999µF capacitance range.



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## Versatimer Switch Kit

**(SC June '11)** Drives a 12V latching relay for switching applications requiring a low current drain. Also provides a battery discharge feature for use with SLA batteries. In-built timer (1s-5hrs) can be triggered from external contacts.

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# CGA-to-VGA Video Converter

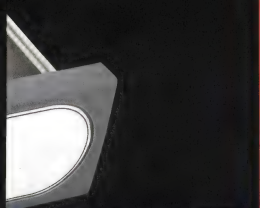
## ... for legacy computer systems

**Do you have an old Amiga, Commodore 128, Microbee, Apple or Tandy CoCo 3 computer that you would like to fire up again? Sure, it will be a nostalgia trip but you may not have a suitable CGA monitor – they were obsolete years ago! This CGA-to-VGA Video Converter from Microbee Technology will allow you to use any recent model LCD or CRT monitor that has a VGA input.**

TINKERING WITH old computers, otherwise known as "retro-computing", has become quite popular over the last few years for various reasons. Firing up these old machines allows you to visit a time when home computers first became affordable and widely available, back in the late 1970s and early 1980s.

For some, this means revisiting the start of their career in electronics and computing. For others, it was the start of a love of gaming. For other groups, it was a chance to tinker with the hardware of these machines – getting the soldering iron out and adding memory chips, interfacing to external hardware, controlling relays, reading

By Ewan Wordsworth
Director, Microbee Technology Pty Ltd



Left: the CGA-To-VGA Video Converter is built into a standard ABS case and is based on a commercial video scaler board (designated the GBS-8200). It's interfaced to the computer via an RGB Intensity Board (at the lefthand end) which you assemble yourself.

Right: the unit works with virtually any PC that has a CGA video output, including the Apple IIGS as shown here.

analog signals, decoding and listening in on radio teletype and weather facsimile transmissions and so on.

The list of hardware projects was endless. But now, if you want to fire up one of these old machines and obtain a full colour display, it isn't so easy unless you have a working colour monitor for your old machine stashed away in a cupboard somewhere.

Just plugging in to a VGA monitor will not work or it may only "half work". The complete solution is the Microbee CGA-to-VGA Video Converter. This kit is based around a common commercial video scaler board, the GBS-8200 v4 which is readily available via the internet. It is widely used to convert arcade machines to use VGA CRT or LCD monitors.

## GBS-8200 drawbacks

The GBS-8200 scaler board takes analog RGB signals with scan rates of 15kHz (CGA) or 21kHz (EGA) and scales the video to suit a VGA monitor with a scanning rate of 31kHz. But while the GBS-8200 board is good on its own, it does have a number of drawbacks.

Firstly, the scaler board requires "clean" horizontal and vertical sync signals. If these are not clean, there is likely to be display jumping and poor picture sharpness. Also, the analog input to the GBS-8200 board does not cater for a true CGA colour output. The CGA interface standard provides digital (TTL level) RGB signals, plus an INTENSITY signal, giving eight colours with two levels of brightness; ie, 16 colours in total.

To fully implement the CGA colour set, the INTENSITY level needs to be used to scale the RGB signals to create an analog output. Once these items are taken care of, the rest of the work is done by the GBS-8200 scaler board.

In this case, the drawbacks are overcome by adding a custom input board from Microbee – the **RGB + Intensity -to-Analog Adapter**, to give it its full description. From here on, we will refer to it as the **RGB Intensity Board**.

While this project is designed primarily for use with Microbee Premium series computers, it can also be used with a number of other older computers including the IBM PC (and its numerous clones), Apple IIGS, Commodore 128, Amiga and Tandy CoCo 3. Other computers that have a 15kHz scan rate and either analog or digital RGB output signals should work with this circuit as well.

## Circuit details

Now refer to Fig.1 which shows the circuit details of the Microbee RGB Intensity Board. It employs two MAX4619 analog multiplexers (IC1 &

## Parts List

### Short-Form Kit

1 Microbee double-sided PCB with plated through holes, Part No. 21-01101-01
1 SPST 90° PCB-mount mini toggle switch
4 SMD 1206 inductors, 600Ω @ 100MHz (L1-L4)
3 2-way pin headers, 0.1-inch pitch (JP1,JP2,JP3)
1 PCB-mount 90° female DB9 socket
1 24-pin DIL socket
1 M3 x 6mm screw & nut

**Semiconductors**

2 MAX4619 CMOS analog switches (IC1 & IC2)
1 PAL22V10 PAL IC, programmed by Microbee (IC3)
1 74HC14 hex Schmitt trigger inverter (IC4)
1 7805 3-terminal regulator (REG1)
1 1N4004 silicon diode (D1)

**Capacitors**

2 100µF 16V electrolytic
5 100nF MMC
6 33pF MMC

**Resistors** (0.25W, 5%)

| | |
|---|---|
| 3 4.7kΩ | 3 330Ω |
| 3 680Ω | 1 270Ω |
| 2 470Ω | 1 82Ω |

### Full Kit

1 short form kit (as listed above)
1 modified GBS-8200 video scaler board & cables
1 drilled and routed ABS case, 200 x 120 x 40mm
1 set of mounting hardware & rubber feet
1 2m-long DB9/M to DB9/M cable

**Power Supply** (not supplied): 7.5-12V DC @ 1A or 5V DC regulated @ 1A (see text)

### Where To Buy The Kits

Both the short-form kit and full kit are available from Microbee Technology Pty Ltd – see www.microbeetechnology.com.au for the details.

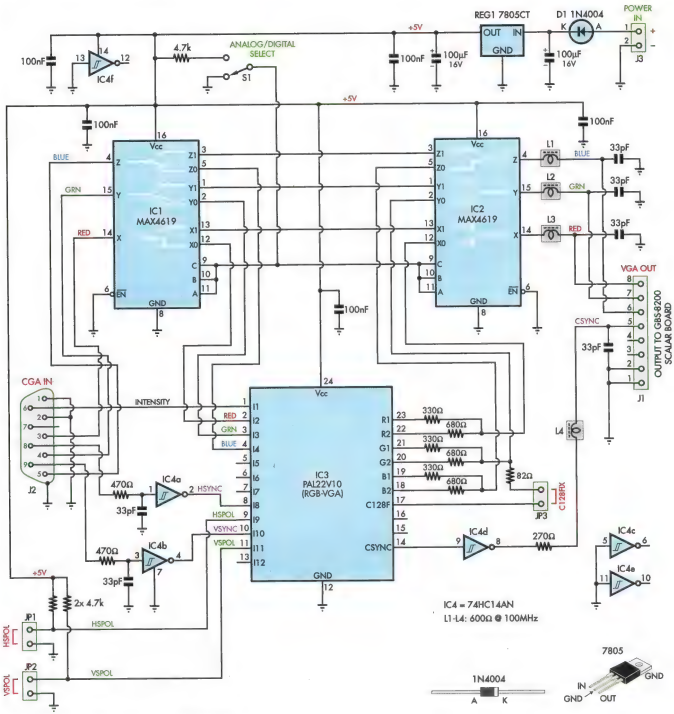
**Top & above: the CGA-To-VGA Video Converter also works with old Microbee & Tandy CoCo 3 computers, as well as the IBM PC, Amiga & Commodore 128.**

IC2), together with a PAL (Programmable Array Logic) device (IC3). IC3 contains the logic that provides the digital-to-analog conversion with the correct colour map for the CGA standard.

Switch S1 selects between the analog and digital RGB modes by switching the two analog multiplexers to either pass through the analog signal or divert the digital RGB signals through IC3. The PAL (IC3) then produces two red (R1 & R2), two green (G1 & G2) and two blue (B1 & B2) outputs at pins 18-23.

These pairs of outputs are then summed via 330Ω and 680Ω resistors to give the correct analog voltages. The load that the GBS-8200 board presents for each of R, G & B signals is 75Ω and the aforementioned summing resistors provide a video signal of 0.7V peak and drive the 75-ohm loads via IC2.

The horizontal and vertical sync signals from the CGA input socket (J2) are fed through RC low-pass networks, both consisting of a 470Ω resistor and a 33pF capacitor, before being fed to Schmitt trigger stages IC4a & IC4b




**RGB INTENSITY BOARD** (MICROBEE TECHNOLOGY)

**Fig.1: the circuit for the add-on RGB Intensity PCB. IC1 & IC2 are MAX4619 analog multiplexers which switch the RGB signal lines, while IC3 is a PAL (Programmable Array Logic) device which performs digital-to-analog conversion to provide the correct colour map for the CGA standard.**

(74HC14AN) to square them up and feed them to the PAL (IC3).

IC3 then combines the squared up HSYNC & VSYNC signals to produce a composite sync output which is fed to Schmitt trigger stage IC4d. Sync signals for CGA are normally positive-going but some monitors require negative-going sync signals. Jumpers JP1 & JP2 cater for this.

Finally, the reconstituted RGB and combined sync signals are passed through individual LC low-pass filters which each consist of a surface mount inductor (L1-L4) and a 33pF capacitor. Each of these SMD inductors has an impedance of 600Ω at 100MHz.

Jumper JP3 (C128FIX) corrects the colour output for a Commodore 128 computer – see the accompanying panel for details.

Power for the RGB Intensity Board comes from the GBS-8200 scaler board and this is fed in via reverse polarity

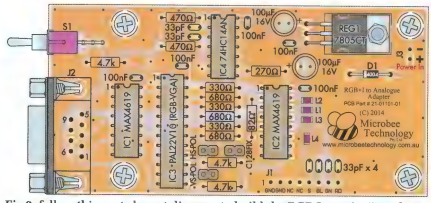



**Fig.2: follow this parts layout diagram to build the RGB Intensity Board. Its J1 output is connected to the GBS-8200 scaler board via a 5-way cable fitted with a header socket (see photo at right), while the power supply inputs are connected to this board via a 2-way cable.**

protection diode D1, A 100µF electrolytic capacitor then filters the output from D1 which is then fed to 7805 3-terminal regulator REG1 to derive a 5V supply rail.

## Construction

Construction is straightforward, with all parts mounted on a double-sided plated-through PCB measuring 100 x 50mm. Fig.2 shows the layout.

Start with the resistors & capacitors, then install inductors L1-L4. These inductors are supplied as surface mount parts on a strip of 8mm-wide tape and it's just a matter of peeling the tape off the backing to remove them. To install them, first melt a small amount of solder onto one pad at the component location. That done, hold the inductor with tweezers, then reheat the solder and slide the inductor into place. You can then solder the other end of the device to its pad.

Next, the front-panel DB9 connector and the switch can be installed, followed by the 24-pin DIL socket for IC3. Take care to ensure that the socket is orientated correctly, ie, notched end towards the top edge of the PCB.

If you decide to power both the GBS-8200 and the adapter board from 5V DC, then regulator REG1 should be omitted. **In that case, it will be necessary to install a link between REG1's vacant input and output pads on the PCB. D1 must also be replaced with a link but watch the supply polarity.**

Alternatively, if you don't have a regulated 5V DC supply, then a supply of 7.5-12V DC is recommended and REG1 (and D1) must be installed to provide 5V for the adaptor board. It's just a matter of bending REG1's leads down through 90° exactly 6mm from its body before fitting it in place. Its metal tab is then secured to the PCB using an M3 x 5mm machine screw and nut, after which its leads are soldered and trimmed.

Be sure to fit diode D1 with the cor-

## Commodore 128: The C128FIX Jumper Option

The Commodore 128 has an 80-column mode that outputs RGB+I digital video on a standard CGA 9-pin D-connector. The colour set is almost identical to the normal CGA colour set, with the exception of dark yellow which appears on Commodore monitors as brown.

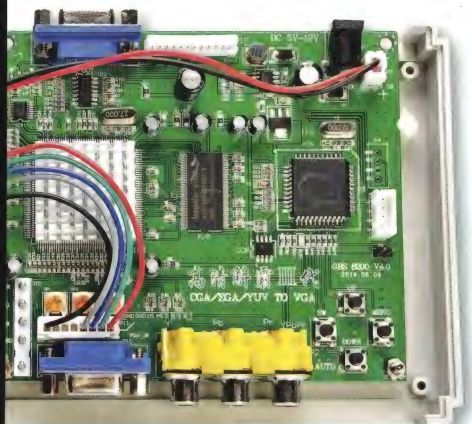
For the purist who wants to represent this colour correctly, the C128FIX jumper should be fitted. Logic inside the PAL (IC3) then pulls pin 17 of this IC low when ever this colour combination is detected. This pin in turn pulls the green level lower via an 82Ω resistor, creating a brown colour instead of yellow at the RGB output.

**Table 2: Capacitor Codes**

| Value | µF Value | IEC Code | EIA Code |
|---|---|---|---|
| 100nF | 0.1µF | 100n | 104 |
| 33pF | NA | 33p | 33 |

**Table 1: Resistor Colour Codes**

| ❑ | No. | Value | 4-Band Code (1%) | 5-Band Code (1%) |
|---|---|---|---|---|
| ❑ | 3 | 4.7kΩ | yellow violet red brown | yellow violet black brown brown |
| ❑ | 3 | 680Ω | blue grey black brown | blue grey black black brown |
| ❑ | 2 | 470Ω | yellow violet brown brown | yellow violet black black brown |
| ❑ | 3 | 330Ω | orange orange brown brown | orange orange black black brown |
| ❑ | 1 | 270Ω | red violet brown brown | red violet black black brown |
| ❑ | 1 | 82Ω | grey red black brown | grey red black gold brown |




**This view shows how the two PCBs are mounted inside the case, with the RGB Intensity Board at left. Note that the VGA & component video inputs at the front of the scalar board are not used and are "blanked off" by the front panel.**

rect polarity, ie, banded end towards the 100µF capacitor.

The two MAX4619 ICs (IC1 & IC2) can now be fitted (watch their orientation) and the power supply cable soldered to the J3 position (red lead to positive, black to negative). That done, solder the RGB input cable (supplied with the GBS-8200 board) to the J1 position with the black (GND) wire at the pin 1 end. The accompanying photos show the wiring details.

Note that only five wires are needed, ie, for pin 1 and pins 5-8. The supplied cable also has a yellow wire on pin 3 and this should be removed.

If you are fitting the boards into the supplied case, you can trim the RGB cable to around 100mm. As always, check your work before applying power. In particular, look for shorts and poor solder joints and check the orientation of all polarised components.

## Getting it going

As stated, the digital mode converts a true CGA digital input (RGB + Intensity) to the proper CGA colour map. This is the mode that's used for the Microbee Premium, Premium Plus & 256TC models, along with regular IBM PCs and numerous other computers.

The analog mode allows the unit to be used with computers that have

**The completed unit can be powered using a 7.5-12V DC 1A plugpack or a well-regulated 5V DC supply (see text). It's just the shot for getting that old "retro" computer going with a recent-model VGA LCD (or CRT) monitor.**

**The completed unit is simple to hook up – all you have to do is connect your computer to the CGA input, connect the VGA output on the rear panel to a suitable monitor and connect a power supply. Note that it's necessary to install the C128FIX jumper on the RGB Intensity Board to get the correct colours from a Commodore 128 computer (see panel).**

true analog outputs, such as the Commodore Amiga (the converter has been tested with the Amiga & works brilliantly!).

Normally, the unit works with positive TTL level HSYNC & VSYNC as the timing signals. If you strike sync problems with an odd-ball system, try installing jumpers on the VS-POL and HS-POL headers. The unit will also work with a composite sync signal.

## Final assembly

Once you have the unit working (it's just a matter of hooking it up to a computer and monitor and trying it out), you can mount the boards in the case which is supplied pre-drilled and routed. The two boards mount on M3 x 6mm tapped Nylon spacers and are secured using M3 x 16mm screws and nuts. In addition, two "side-mount" Nylon stand-offs are used to support the rear of the GBS-8200 scaler board (see photos).

These side-mount stand-offs are necessary because the rear mounting holes in the GBS-8200 PCB are unusable due to the case design.

Once the PCBs are in place, the top of the case can be fitted and the front and rear panels snapped into place to lock the case together.

That's it – the CGA-to-VGA Video Converter is complete. SC

## Modifications To The GBS-8200 Board

While developing this project, we detected a fault in the signal output from the GBS-8200 scaler board under certain conditions. Intermittently, and mostly when the board was cold, there would be "snow" on the video output.

Apparently, this is a common fault with the GBS-8200 and appears to be a result of omitting damping resistors in the SDRAM interface and poor calibration of the SDRAM timing. As a result, Microbee has modified the GBS-8200 scaler boards supplied with their kits for optimal output.

Finally, we recommend setting the VGA monitor to a resolution of 1024 x 768 pixels and setting the sharpness close to maximum.

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## Master Instruments/West Mountain Radio's

# Computerized Battery Analyzer/Charger

Review by Nicholas Vinen

**This instrument connects to a PC and, in association with several optional accessories, can test many different types of battery for capacity, run time, output impedance, cycle life and temperature during discharge. It can handle charging up to 50V/10A and discharging up to 55V/640A/2100W, depending on how many optional "amplifier" modules are connected.**

**In essence, the CBA IV** from West Mountain Radio is a USB-controlled DC constant-current load with voltage and temperature monitoring. The 55V maximum rating means it will work with just about any Nicad, NiMH, Li-Ion, Li-Poly or LiFePO4 battery pack or lead-acid batteries up to 48V nominal (24 cells).

The main unit itself is can discharge a battery at up to 150W/40A (short term) or 100W/20A (continuous), however this can be boosted in 500W increments by adding external "amplifier" modules.

The unit itself is compact, at 90 x 74 x 76mm. It connects to a Windows computer via USB and to a battery via a dual high-current Anderson-type connector.

A cable with this connector attached to short, thick wires is supplied, as is a USB cable, software CD and calibration/test certificate. When running a test, a fan on top of the unit keeps it cool. It runs quite slowly so it doesn't make a racket.

To do more comprehensive testing such as battery life cycle tests, you need to connect the CBA IV Pro to the CBA Charger interface unit. This is essentially a box with a current shunt and relays which connects between the battery under test and a suitable charger of your choosing.

At the start of each charge/discharge cycle, the CBA IV Pro commands the charger interface to connect the charger terminals to the battery terminals by closing a pair of internal relay contacts. At the same time, it closes an auxiliary relay which can be connected across the charger's "start charge" button (if it has one).

There is also a pair of inputs on the charger interface which are wired across the charge complete LED on the charger itself, so that this can relay the signal to the CBA IV Pro, which then disconnects the charger and begins the discharge procedure.

To build a complete battery test rig using the CBA IV Pro, you will need several boxes wired together and a fair amount of desk space to do it.

The system will involve the CBA IV Pro, the controlling computer, the charger interface, the charger, the battery

**The main unit is shown at left, with the charger interface at right. On the facing page is the much larger 500W current sink "amplifier".**

and possibly one or more amplifier units, depending on the discharge rate required.

However in exchange for this, you get a fairly flexible and easy-to-use battery testing system at a reasonable price.

Regarding the software, it is easy to use and we were able to figure out how to set it up and run a test within minutes. We tested it using Windows 7; Vista and (the now defunct) XP are also supported.

The West Mountain Radio website suggests it will also work Windows 8.

## Higher dissipation

The amplifier unit is simply connected in between the CBA IV Pro and the battery. On the battery side, large bronze lug terminals are provided to allow thick wire to be connected as each "amplifier" can sink up to 160A. The CBA IV Pro handles 10% of the load current while the amplifier unit, with its large heatsink and dual fans, dissipates the other 90%.

The amplifier requires a separate 15V DC supply and a 240VAC-rated switchmode brick is supplied with the unit.

For dissipation above 550W total, two or four amplifiers can be connected together. We couldn't find any instructions for doing this in the manual but logically they will need to be connected in parallel.

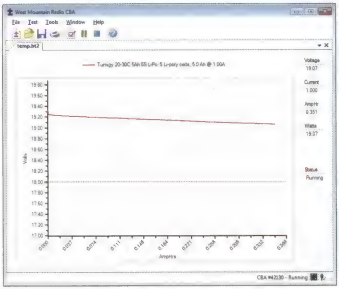
This would be handy for testing high-discharge Li-Po battery packs or large lead-acid batteries. When multiple amplifiers are used, we assume that the fraction of the load handled by the CBA IV Pro reduces proportionally, to 2.5% with the maximum of four amplifiers.

## Software upgrades

The software supplied with the CBA IV Pro allows basic tests to be performed such as battery capacity with constant current load. As supplied, it produces graphs of the results as well as summary figures.

However, some enhanced tests such as constant power loading, cycle testing and temperature graphing (with temperature probe accessory connected) require the purchase of an "Extended Software Upgrade License".

The extended software also allows multiple unit testing (ie, test multiple batteries at the same time), the ability to calibrate out battery lead resistance, pulsed discharge, constant resistance discharge and the ability to use the unit to profile power supplies and solar cells.




**Voltage change for a Li-Po battery pack as it is discharged with a constant current. This, and much more information on battery status is available from your computer.**

We think most users purchasing the CBA IV Pro will want the extended software, which costs USD $119.95 (available via the West Mountain Radio website – www.westmountainradio.com).

## Accuracy

The difference between the CBA IV and CBA IV Pro is that the latter is calibrated for greater accuracy. It is supplied with a calibration certificate and ours shows that the current reading error is <0.5% across the entire range (10mA-9A) and <0.2% error above 150mA. The voltage measurement error is <1% below 5.5V and <0.1% above 5.5V.

## Pricing & availability

If you work with many batteries and have a need for automated testing and analysis, the CBA IV Pro certainly does the job with few hassles. It's best suited to a lab-type environment where it can be permanently set up with all the required chargers and connections for the types of batteries being analysed.

Having said that, hobbyists and smaller operators with the required technical knowledge (eg, people with a lot of power tools) would find it useful too.

For proper analysis capability, you probably need the CBA IV Pro, CBA Charger, a multi-chemistry battery charger (which may need some hardware mods) and the extended software.

All the hardware mentioned above is distributed in Australia and New Zealand by Master Instruments. The CBA IV Pro costs $319.95, the charger interface $169.95, the amplifier modules $1125.95 and the temperature probe $22.95 (all prices include GST).

For enquiries, visit www.master-instruments.com.au or call them on one of the following numbers: NSW (02) 9519 1200, Vic (03) 9872 6422, Qld (07) 5546 1676 or WA (08) 9302 5444. SC

By Ian Batty

# Trapped in Germanium Valley: The Philco T7 Transistor Portable Radio

## . . . early to market & early to retire

**Released in 1956, the T7 was Philco's first portable transistor radio. It used the company's proprietary SBT germanium transistors and compared favourably with other sets of the era but was soon overtaken by sets based on silicon transistors.**

THE PHILADELPHIA Storage Battery Company was registered in 1906 and began releasing products under the Philco brand name in 1919. As noted in my article on Philco's Safari portable TV set in the January 2014 issue, the company was an early adopter of transistor technology, releasing their proprietary Surface Barrier Transistors (SBTs) in 1953.

At that time, alloy-junction transistors (such as the OC45) were restricted to a maximum frequency of about 15MHz. The limiting factor was how thin the base region could reliably be made. As a result, Arthur Varela of Philco reasoned that electrical etching would be more controllable than the somewhat random process of high-temperature alloying and so he invented the surface-barrier transistor (SBT) process.

In this, the base slice was held vertically and chemically etched away by very fine sprays to form emitter and base "wells" on opposite sides of the slice. Then, electrochemical deposition "plated" the emitter and collector regions onto the base slice, creating a fully-working transistor. The actual junctions worked just fine but with somewhat lower barrier potentials than for alloy-junction devices.

Surface-barrier transistors offered high-frequency operation to at least 30MHz. Adding diffusion to the process (MADT – microalloy diffused-base transistor) pushed frequencies to some 200MHz.

Philco devices (and their licensed equivalents from US Sprague and English Semiconductors Ltd) are easily recognised by their distinctive TO24 and TO25 "bullet" cases. These are shown in the photos on the facing page.

Philco's 1955 release of "the world's first all-transistor car radio" and their "fully transistorised portable phonograph" (released the same year) should have ensured that Philco remained a major consumer electronics manufacturer. However, Philips, working in parallel, were developing their alloy-diffused technology, eventually yielding the landmark AF186 transistor. This could be used as an RF amplifier at frequencies up to 860MHz.

Outstanding as this was, germanium's days were numbered with the rapid development of high-performance silicon technologies: mesa and planar.

With their ability to form an impervious surface layer of silicon dioxide (glass), silicon devices allowed cheap plastic encapsulation. Mass-production lithography also allowed many tens of devices to be made on one silicon die, resulting in skyrocketing volumes and nose-diving costs of production.

Philco missed this new silicon technology wave. Surface-barrier and other pre-lithographic technologies suffered from "one at a time" production techniques and their associated high costs of manufacture. The failure to move to silicon meant that Philco's lead in manufacturing had faded by the early 1960s to re-supply for existing equipment. Their specialist solid-state

ground-based and aircraft computers, along with ground station equipment for the space exploration programs of Project Mercury, could not save Philco.

The company eventually filed for bankruptcy in 1961 and was bought out by the Ford Motor Company.

## Philco's T7 radio

While I dislike overblown descriptions, I just have to use the word "stunning" for this design. Its stark tuning dial with its arrowhead design just stands out against the white cabinet. And why not add some gilt trim to complete the effect? Put it among any number of contemporaries and even the casual viewer's eye will linger over this one.

My only reservation is the tuning-dial thumbwheel. It's well-designed but the red lettering doesn't stand out against the black background as well as I'd like. Given the stark black-on-white of the cabinet, I'd have used white dial markings both for legibility and for aesthetics. Nevertheless, the T7 is an eye-catching piece of 1950s industrial design, even when fitted inside its leather case.

Internally, most of the parts are mounted on a PCB and this is secured to a metal chassis that also holds the speaker. The chassis is secured by screws to the inside of the plastic case, while the PCB is secured by twisted metal tabs. This means that the PCB is best left in place unless removing it is absolutely necessary, since there is a risk of breaking off these tabs.

## Design details

The "first" of anything always interests me. That's because the engineers have created a solution to a problem that's sometimes well-understood but more often only vaguely perceived.

In this case, the obvious aim was to make an all-transistor radio that could be carried around and used anywhere. But how many transistors should be used in the design?

Rival company Regency, cutting costs savagely, began with eight transistors and finished with a mere four in their landmark TR-1 design (see SILICON CHIP, April 2013). The result was a handsome "coat-pocket" set that performed well enough in quiet living rooms in the city.

But at a football game or in the country? It was "a toy that didn't come at a toy price", as one wag put it.

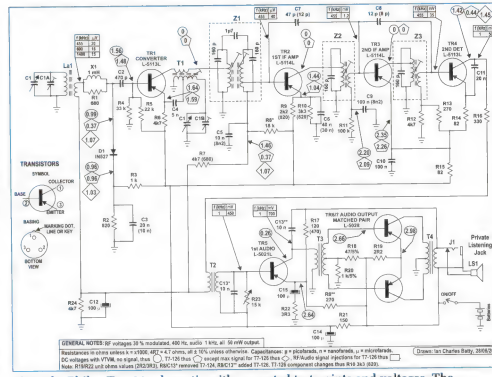



**Fig.1: the Philco T7-124 schematic with suggested test points and voltages. The changes made for the T7-126 are shown in brackets. The set is a 7-transistor superhet design with TR1 functioning as the converter, TR2 & TR3 as IF amplifier stages, TR4 as the detector and TR5-TR7 as an audio amplifier.**

By contrast, industrial giant Raytheon, with a massive market presence in the industrial, military and domestic arenas and a reputation to uphold, went for a "picnic portable". Designated the 8-TP-1, it boasted eight transistors and a performance that equalled similar-sized valve portables.

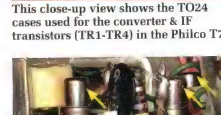
Philco, eager to carve out market share, went one less. Their T7 transistor radio not only challenged Raytheon's "big set performance" but also targeted the personal portable/coat-pocket niche that was also being viewed by compatriot Zenith and by foreign start-up Sony.

## Circuit details

Fig.1 shows the circuit details of the Philco T7. It's basically a 7-transistor design using PNP transistors TR1-TR7 and a 455kHz IF strip. Note that although this set uses PNP transistors, the battery supply is negative to ground rather than the positive to ground as in most contemporary Australian sets.

The following description is for the first "124" series, with the later "126" series modifications noted on the circuit diagram. Note that many online circuit copies do not show decimal points clearly (R22 is a 3.3Ω resistor, while C10 is a 0.1µF capacitor).

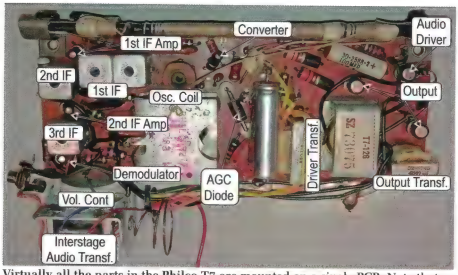
**This close-up view shows the TO24 cases used for the converter & IF transistors (TR1-TR4) in the Philco T7.**



**The audio-stage transistors (TR5-TR7) used the larger TO25 cases.**

TR1 functions as a fairly conventional combined mixer-oscillator stage (ie, as a converter). Like Raytheon's 8TR/7TR chassis, Philco applied AGC to the converter stage to give the most effective gain control possible. However, in Raytheon's set, the AGC controlled only the mixer stage and so there was no drift from the separate local oscillator.

So how did Philco fix this problem




**Virtually all the parts in the Philco T7 are mounted on a single PCB. Note that the first IF transformer (Z1) actually has its windings in two separate cans, while the second and third IF transformers are each in a single can. The unit just needed alignment adjustments to get it going again.**

**The PCB is mounted behind a chassis plate which also carries the loudspeaker and the volume control at bottom right. The dial fits over the tuning gang shaft at centre right and features red markings on a black background.**

with just one transistor in the converter stage?

Easy – use a diode attenuator (D1) in the antenna circuit. This technique was similar to that employed in some later sets which had an attenuator diode in the primary of the first IF transformer. Philco's circuit had the advantage of reducing signals before the mixer, effectively preventing overload on strong of signals. The converter itself operates with fixed bias, as do almost all single-transistor designs.

## IF stages

Two IF amplifier stages (TR2 & TR3) follow, with conventional transformer coupling. The first IF (Z1) has tuned (and tapped) primary and secondary windings. In reality, my set has two separate cans for these windings, with the associated 1.7pF capacitor providing top coupling between the two tuned circuits.

As with the Pye Jetliner, capacitive coupling is an effective (if unusual) means of coupling two single-tuned transformers. This gives more compact IF transformers and eliminates the need to turn the set over to adjust a "bottom" ferrite core.

The second and third stages (Z2 & Z3) use tuned primaries and un-tuned low-impedance secondaries.

In common with most other designs, AGC is applied to the base of the first IF amplifier (TR2) while the second stage runs at full gain with fixed bias. Note that although Philco's surface-barrier transistors work somewhat differently from the more-familiar OC44/45 alloy-junction types, their high collector-base capacitances still require neutralisation in both IF stages. They also have lower base-emitter voltages than the OC44/45 types.

## AGC circuitry

The demodulator (or detector), like that in the Raytheon 8RT1 chassis, consists of a transistor (TR4) operating just at cut-off in class-B (R12 & R13 set the bias). Compared to a diode demodulator, this class-B version provides some audio gain plus DC amplification for the AGC circuit.

As shown, TR4's collector current passes through R16 and the primary of audio interstage transformer T2, with the resulting audio signal then fed to T2's secondary. Bypass capacitor C12 filters the audio component across R24, leaving only the DC component to derive an AGC voltage (a simplified version of this circuit, with positive earthing, is shown in Fig.2).

This AGC voltage is applied directly to the anode of AGC diode D1. Its cathode is fixed at -0.96V by a voltage divider based on resistors R3 & R2, so that it is "just out" of conduction with no applied AGC.

In operation, the stronger the received RF signal, the greater TR4's collector current and the higher the AGC voltage across R24. This pulls the AGC voltage towards the positive supply rail, thereby making D1's anode positive with respect to its cathode. As a result, D1 begins conducting and "damps" the signal at the converter base, thus reducing the signal reaching the converter.

## Audio circuitry

The audio signal from transformer T2 is fed to a conventional 2-stage transistor power amplifier (TR5-TR7). TR5 operates as a class-A driver stage and this drives the primary of audio transformer T3 which acts as a phase splitter. T3's centre-tapped secondary output then drives transistors TR6 & TR7 which are configured as a class-B push-pull output stage.

One neat design trick pulled by Philco is that TR5 is biased by the voltage drop across R21 which also serves as the decoupling resistor for the low-power stages. Talk about squeezing the last drop of juice out of a component!

**The T7 radio was protected by an attractive leather case with a carrying strap. It's necessary to open the front flap in order to tune the radio and adjust the volume control.**

Volume control is achieved by rheostat-connected potentiometer R23. This is connected directly across transformer T2's secondary so that it acts as a variable shunt. It's less elegant than a true potentiometer but effective nonetheless.

The output stage operates with fixed bias, as set by divider resistors R18 and R20. In addition, there's a small amount of local negative feedback via shared emitter resistor R19. This resistor also helps balance any differences in gain that might exist between output transistors TR6 & TR7.

The Philco T7 also uses feedback for the audio driver/output stages. That's done using feedback resistor R17 which couples a small signal from one of the speaker terminals back to the emitter of driver transistor TR5. This also implies an audio amplifier voltage gain of about 40 (the ratio of R17 to R22). Finally, the audio from the output transformer (T4) is fed to a 15Ω 2.5-inch (64mm) loudspeaker (LS1) via a headphone jack.

## Getting it going

Cosmetically, my T7 set was in tip-top condition when I acquired it. But electrically? – it was very quiet and that's always a worry with any set that has five or more transistors.

Well, a quick tweak of the IFs couldn't possibly hurt, could it? At this point, you may be starting to cringe. Some collectors are firmly of the view that if a set has been left alone, you shouldn't expect "demon drift" in the IFs to have degraded the set's performance. It's often a wise to leave these settings alone, especially with complex equipment such as FM radios and (especially) TV sets.

But I was rewarded by tweaking the

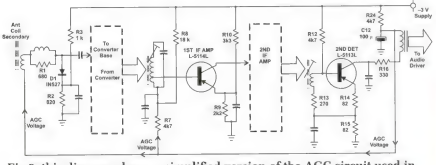



**Fig.2: this diagram shows a simplified version of the AGC circuit used in the Philco T7. The AGC voltage is derived from the primary of the audio interstage transformer and is applied directly to the anode of AGC diode D1 and to the base of the first IF amplifier (TR2) via a 4.7kΩ resistor. D1's cathode is fixed at -0.96V by a voltage divider based on resistors R3 & R2, so that it is "just out" of conduction with no applied AGC.**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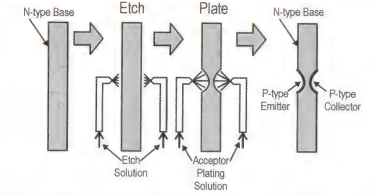


**Fig.3: the SBT manufacturing process. The base slice was held vertically and chemically etched away by very fine sprays to form emitter and base "wells" on opposite sides of the slice. Electrochemical deposition was then used to "plate" the emitter and collector regions onto the base slice, creating a fully-working transistor.**

IFs on this simple set. Starting with barely any reception, each adjustment of the IF coils brought in more and more signal. The set then really came alive when I adjusted the oscillator coil slug (T1) and the two associated trimmers.

A light spray of contact cleaner on the volume control and this set was done and dusted. In my opinion, it was now working just as well as it was when it has handed over to its original owner, some 57 years ago.

By the way, the original T7-124 was introduced in 1956 for the 1957 model year. By contrast, the one I have is a slightly later T7-126 model. The Philco-manufactured tuning gang bears a stamping with a "748" code, implying the 48th week of 1957 for this set.

## How good is it?

So how good is it compared to the 7-transistor Raytheon T2500 (SILICON CHIP, June 2013)? Well, leaving aside the T2500's higher audio output and better overall response (two speakers and a larger cabinet), it's a good match.

The Philco T7 manages a sensitivity of around 220µV/m at 600kHz and 170µV/m at 1400kHz. Its 1400kHz performance is a bit noisy at this level

**An unusual hour-glass shaped tuning dial is a feature of the T7. The tuning thumbwheel has red lettering on a black background but white lettering would have been easier to read.**

though, with a signal-to-noise ratio of about 17dB. A 20dB signal-to-noise ratio requires an RF signal level of about 200µV/m.

These figures are pretty similar to Raytheon's T2500. However, the Raytheon set makes up for its single IF amplifier stage with an extra (third) audio stage, making it a bit noisy at minimum volume. Philco's approach of two IF amplifier stages and only two audio stages pays off and the T7 is quiet at minimum volume.

The selectivity is around ±19kHz at -60dB while the AGC is excellent, with only a 6dB increase in audio output over the range from 200µV/m to around 40mV/m (the effective AGC range is some 46dB). It does go into overload soon after but 40mV/m is indeed a very strong signal. The extensive AGC range justified the "diode attenuator" approach and foreshadowed the Mullard implementation by some four years.

Audio performance is a mixed bag, with the set going into clipping at an output of 80mW. Given the low supply rail of only 3V and the fact that many 6V sets only manage around 250mW, this is still quite respectable.

The audio response (starting at 400Hz) between the volume control and the speaker terminals rises by about 2dB at 3kHz and then remains fairly flat until dropping by -3dB below the 400Hz reference at 37kHz (some high-frequency roll-off would have been nice). The low-frequency response following the volume control goes down to around 110Hz. Unfortunately, it only manages about 500-1800Hz from the antenna to the speaker.

The THD (total harmonic distortion) is reasonably low, the figures being 2.2% at 10mW, 3% at 50mW and 8% at 100mW. With a "flat battery" supply of 1.5V, an oscilloscope trace shows visible crossover distortion at 10mW output and the THD increases to around 5%. The set manages a maximum output of around 20mW and 9% THD with the low battery.

## Would I buy another?

So would I buy another one? Well, it is tempting – one for the lounge room and one for the workshop display shelf. As I write this, there's one being advertised on-line for just under $300 but I really do need to stop somewhere.

## Different version

The original T7-124 and T17-126 are quite similar, as Fig.1 shows. Note that I've omitted the link connections (L1-L9) that connect to the PCB for clarity.

So what are the differences? First, AGC diode D1 and interstage transformer T2 have been removed from the T7X (model 128). Output transformer T4 has also been removed. Instead, the TX7 employs a single-ended push-pull "output-transformerless" circuit that couples directly to the loudspeaker, with the return connection going to a 1.5V tap on the 3V battery. This output design will be described in an upcoming article on Philips portables. SC

## References

(1) Thanks to Ernst Erb for his Radio Museum site at: www.radiomuseum.org This site has service data for two T7 models (the 124 & the 126) and for the T7X (model 128).
(2) Surface-barrier transistors are described at:
http://www.rfcafe.com/references/radio-news/amazing-surface-barrier-transistor-august-1957-radio-tv-news.htm
http://en.wikipedia.org/wiki/Surface-barrier_transistor
http://www.google.com/patents/US2843809

# ASK SILICON CHIP

**Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au**

## Speed control for a milling machine

Did you ever design a power supply with the following specifications: 230VAC to 230V DC with speed control and reverse @ 1100W?

About a year ago, I bought a milling machine for over $5000. I live in Mount Morgan, not far from the power station that supplies the coal mines at Blackwater and district. About a month ago we got a big surge of power over 500V. The power station had to start another generator for the mine to move a drag line scoop. And as we are so close (about 2km) we got the full blast of power before the mine did and it damaged my mill's power supply. I have contacted the manufacturer in China but I cannot get any response.

I thought that if I could make a power supply for the machine it would save me a lot of time and trouble. The power supply to the machine drives two DC motors, the main motor and a smaller one that drives the table. (A. P., via email).

● It is possible that a speed controller such as the 240V 10A Motor Speed Controller from February and March 2014 is suitable. This design rectifies the mains to provide DC to a motor.

The speed is controlled by chopping up the half-wave rectified waveform into about 1kHz pulses. It is suited to series or universal motors (ie, those with brushes and commutators. It does not suit induction motors. For those you need to refer to our articles on the Induction Motor Speed Controller.

## Temperature control of an air-conditioner

I guess you are always looking for new project ideas. A missing link, in my mind at least, is a way that a computer could be used to control air-conditioning. We have several split systems that have handheld IR remotes. I am about to put in a 5kW solar system, not to sell power but hopefully to use what is generated to both heat and cool our home and business.

The problem is that if heat or A/C isn't needed, the timer on the remote would turn it on anyway. What would be better would be a controller hooked up to a temperature sensor and a computer could make a decision for the system to be turned on. (E. P., via email).

● Your idea for controlling the air-conditioner is good but we wonder if you really need a micro. Perhaps you could do it with our Tempmaster project (August 2014) which has a relay output. You can see a 2-page review of the article at www.siliconchip.com.au/Issue/2014/August/The+Tempmaster+Thermostat+Mk.3

## Inaccurate readings on the LC meter

I built the High-Accuracy Digital LC Meter (May 2008) a while back and it has been very useful so far. However, I have recently noticed that there seems to be a problem with it when measuring axial-lead ceramic capacitors. I have two that I pulled from a TV set while troubleshooting it. Both are marked with brown-black-orange-white codes which indicate 10nF and the schematic agrees with this.

On connecting them to my meter the display starts off showing a value around 160nF which then rises before stabilising at 200nF. At first I thought both capacitors were bad but they seem to test fine as 10nF on a Metex M-4650CR DMM. All I can think is that perhaps the capacitors have some inductance due to their design which is confusing the meter but I am unsure.

Can you shed some light on this problem? (A. N., via email).

● We haven't heard of that gross misreading problem before but it may well be caused by either dielectric leakage or spurious inductance in those par-

## Multi-Spark CDI On A 3-Cylinder Daihatsu Charade

The recent Multi-Spark CDI is a great revision of the September 1997 design by John Clarke! I still have two of these units in use on 3-cylinder Daihatsu Charade motor cars.

I have a few quick questions, please. In table 1 (for a 6-cylinder engine), should I halve or double the RPM for a 3-cylinder engine? Are there any disadvantages in disabling the multi-spark function when dealing with a cold cranky standard engine?

On winter mornings I had the starter motor happily spin over but the spark plugs would not fire, once the 40Ah batteries were over 12 months old. I eventually had to connect a small 12V gel battery, via a relay when in the Start position, to fix this problem! Could you please suggest any further circuitry modifications to allow for the sagging battery voltage on a cold start? (B. C., Dungog, NSW).

● The CDI was designed to work down to around 9V. If the voltage drops below this, consider revising the wiring from the CDI to the main battery using a relay that switches on the CDI when ignition is switched on. The relay contacts can then connect power to the CDI directly from the battery terminals via a fuse.

It is unlikely that the battery itself drops below 9V and any extra voltage drop is possibly due to the vehicle wiring. Alternatively, there could be a drop in the chassis supply from battery negative to chassis through contact voltage loss or losses in the wires.

As noted in the Mailbag pages of this issue, the low voltage cut-out could be improved for operation down to about 7V by removing the 10kΩ resistor connecting pin 2 of IC1 to ground.

## DC-DC Converter For Valve Amplifier HT Supply

I have been looking at the Multi-Spark Capacitor Discharge Ignition circuit. The DC-DC boost converter looks interesting and I would like to build this style of circuit to produce HT voltage for a valve hifi amplifier. Would you know how much current is achievable for the 300V DC output? I am probably looking for 150mA.

If 600V DC @ 150mA was needed, could two of these converter outputs be put in series? Or maybe it would be easier to run one converter and double the secondary winding turns to suit? Would I need to use a larger transformer core etc for T1?

The DC input voltage could be raised to maybe 24/30V DC if need be. Do you think that the PCB layout is critical for my audio application? Could a diecast box act as a Faraday shield? Finally, could the operating frequency be increased easily? (J. L., via email).

● Unfortunately, the DC-DC Converter is not rated for the 90W you require (600V at 150mA) . The DC-DC Converter cannot be connected in series with another since the output is referenced to the ground supply.

You could design the DC-DC converter along the same lines as that used in the Multi-Spark Capacitor Discharge Ignition but using say an ETD34 transformer core and bobbin, with thicker primary windings and more secondary winding turns for the 600V output.

IC2 (TC4427) is not suitable for supplies above 18V maximum so maybe 16V zener ZD1 could be used to provide a 16V supply for IC1 and IC2 using a suitable value and rating for the limiting resistor (currently 10Ω 0.5W). The low-voltage dropout for IC1 could be disabled by removing the 8.2kΩ resistor at pin 2 of IC1 and replacing diode D1 with the 10kΩ resistor that connects pin 2 to ground.

Overall, the PCB design is important to effectively bypass the supply at the transformer. The feedback resistors would need changing at IC1's pin 16 input to give 600V and higher-rated bypass capacitors with a greater ripple current rating would be required. A diecast box can be used for shielding and heatsinking and would be desirable.

The operating frequency is dependent on the transformer core and the winding wire. Note that skin effect can effectively reduce the usable wire cross sectional area and often flat sheet copper or Litz wire is used for the windings at higher frequencies. This can be difficult for the home constructor.

ticular axial-lead ceramic capacitors, as you suggest. There does not seem to be any other good explanation.

## Query about valve output transformers

Congratulations for an interesting magazine; I've been reading SILICON CHIP for many years. Regarding the Currawong amplifier and the use of line transformers for the output transformers, I initially misread the text and thought that you were using power transformers. I remembered my days as an apprentice years ago when I was working for Pye in New Zealand.

Part of my time there was spent winding one-off transformers as replacements for failed items sent in by repair shops. I had a large range of wire gauges and the only winding machine with a counter that would count backwards. Sometimes it would be necessary to de-stack the laminations and unwind the winding from the bobbin then rebuild a replacement unit.

I wound both power transformers and output transformers and remember that the E & I stacking was alternate Es & Is for power transformers and all Es in from the same side with all Is separated by a thin sheet of interleave paper for output transformers. I don't remember the reason for this so could you enlighten me? (J. D., via email).

● The reason for the interleave paper between the E & I laminations is to provide an air gap in the core of known and repeatable dimension. The air gap modifies the B-H curve of transformer. In simple language, this means that it reduces the permeability and increases the required magnetising current.

The usual reason for doing this is to prevent the gross non-linear performance which would otherwise occur in an audio output transformer in a single-ended valve amplifier. Since the output valve's plate current flows in the transformer's primary winding, the resulting DC magnetisation reduces the amount of extra magnetisation which needs to occur when there is an audio signal present before severe distortion occurs.

Push-pull amplifiers avoid this problem because the valve plate currents flow in the two halves of the transformer primary and the resulting magnetisation from the DC currents is cancelled.

## Enquiry about old oscilloscope projects

After getting the DVD on all the issues of *R,TV&H*, I am interested in the *R,TV&H* 1963 and EA 1966 scopes by Jamieson Rowe as I either have the major components or have access to them. I am however not very familiar with valve circuits and so not confident about modifications on these circuits.

I am interested in building the 1966 version from *Electronics Australia* but with some of the circuitry from the 1963 design. The main reason is to get the frequency response of the 1963 design in the 1966 design and also retrace blanking.

I would like to have the Transitron-Miller circuit in the 1966 design. Is it possible with the smaller chassis as the original in 1963 had a large shield plate immediately behind the front panel? Also space must be found for an extra valve. There seems to be space between the three valves in the horizontal drive circuitry in the 1966 chassis blueprint drawing. Maybe the chassis needs to be made wider? Some rearrangement would be necessary.

Can the X shift circuitry in the 1963 circuit be modified to be similar to the 1966 circuit? I am not sure about the isolating input capacitor to the X amplifier which is not present in the 1963 design. I can change all diodes to silicon types. This means that the triode connected as a diode is redundant, so can it be paralleled with the other triode used as a cathode follower in the timebase circuit?

What about additional peaking coils? I see peaking coils for the Y plates but these are coming off a cathode follower. I guess some circuitry can be replaced with transistor circuitry but there have

been no transistor scopes in EA except reviews. (K. V., via email).

● Unfortunately, we are simply not in a position to give detailed answers about projects that were described in the forerunner to SILICON CHIP magazine some 50 years ago. None of the modifications you propose or ask about are simple.

In practical terms, we suggest you build the 1966 scope and depending on how satisfied you are with its performance, you then might possibly modify it to include features from the earlier design. However, we should warn that the performance of these quite basic oscilloscopes is rudimentary compared with today's cheap digital scopes. In fact, the performance of the USB digital scopes reviewed in this issue is far beyond anything that most engineers would have dreamed of 50 years ago.

## Stereo receiver power consumption

I have a Sony AV/receiver with no speakers connected (just headphones plugged in) and the unit's power consumption is rated at 240W. My question is, with this arrangement would the AV/receiver consume less power? (D. S., via email).

● The power consumption of your receiver when driving headphones or with no program signal coming from the loudspeakers is probably only about 15-25W. With speakers connected and with the music turned up, the average power consumption is probably only around 50W.

The only way to confirm these figures is to use an AC power consumption meter which you can buy cheaply from Jaycar and other retail outlets. Aldi stores occasionally have a very good one, branded "Vivid".

## Orbital Sander Not Affected By Mains Frequency

I have an orbital sander that used to work great on 60Hz while I was in the USA but now, despite my large 240V to 115VAC transformers at 50Hz, the eccentric shaft drive in the sander shakes my hand off. Evidently, it is critical that it runs at the designed 12,000 RPM.

Does SILICON CHIP have a 500W 50Hz to 60Hz converter design or any suggestions? (D. K., via email).

● Orbital sanders usually have a counterweight to counterbalance an imbalanced sander plate that is off centre. The fact that the motor is rated to run at 12,000 RPM suggests that is powered by a series motor, as are virtually all mains-powered hand tools. So the frequency of the AC mains supply should have little effect. It is more likely that a misaligned counterweight is causing the severe vibration. We have not published a 50 to 60Hz converter.

## Filters for digital TV interference

The article in the November 2014 issue entitled "The Digital Dividend, TV Channel Restack" answered a lot of questions for me and probably for a lot of your readers.

It seems that it would be advantageous for a filter to be designed for each of the five frequency blocks as listed in Fig.2. Readers could select the appropriate filter design for the frequency block used in their area and make one up to reject interference outside their block.

For users of the K274 masthead amplifier, the filter could be incorporated into that housing. Would such filters be an appropriate project for the magazine? (B. H., via email).

● We are not aware that interference is generally a problem at this stage. The message from the article is that you should use an antenna to suit your reception area and add an LTE filter if interference is a problem.

## Recycling a cordless drill

A great many people are concerned about waste and the throw-away culture which seems all pervasive now. Like many people, I have a battery-operated drill driver. When the batteries started to fail to hold a charge I was


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## DC-DC Inverter For Vintage Radio HT Supply

I wonder if you have ever published a project for a DC:DC converter to go from 12V to 90V @ 20mA to replace the "B" battery in an old battery valve radio (Zenith G500)? I'd like to make my old Zenith radio truly portable and I have a few spare 12V gel batteries.

I've already modified a buck converter to provide the 9VDC @ 70mA for the filaments ("A" battery). Maybe there's an inverter that can be easily modified to do the job? I'm looking for something fairly simple (no PICs please!) with a step-up transformer that is readily available, cheap, and/or one that's easy to wind myself.

I guess the CLASSIC-D DC-DC inverter could be modified to do the job but it's a lot of overkill. I just need some reasonably smooth DC at about 75-90V and about 20mA. (B. M., via email).

● The Digital Insulation Tester from June 2010 includes a low-power DC-DC converter. Its output windings and the feedback voltage divider could be modified to produce 90V rather than the original 250V, 500V or 1000V. The design uses standard parts: MC34063, IRF540, a ferrite pot core and other common parts.

Alternatively, see the Nixie Clock power supply circuit in this issue.

faced with either buying new batteries or replacing the whole drill, which is actually a viable option financially.

Either option just adds to the mountain of waste we generate. Given that this is the fourth time in the last 10 years that this has happened I started to think about alternatives. The drill is used for the majority of time in my workshop, so battery power is irrelevant. I have old batteries so a physical connection to the power leads inside the case is reasonably simple.

The batteries are nominally 14.4V. I measured the current drawn with the drill rotating freely and it topped out at about 9A. The thing I cannot establish is how much current is drawn when the drill bit or screwdriver bit stalls in the work because my current measuring capacity is limited to 10A.

Given that the life of a drill such as this far exceeds the life of the batteries supplied with it, do you think it would be practical to design a power supply operated from the mains that could power a drill such as this? If the stall current was an issue, would it be possible to incorporate a current-sensing system that could disconnect the power once the supply capacity was reached? Would this make an interesting project for your magazine? (B. D, Hope Valley, SA).

● We covered this exact topic in the December 2010 issue with an article entitled "Recycle Your Cordless Drill – Make It Corded". There we discussed the various power supply options, including 12V batteries, 12V battery chargers and the 12V outputs of PC power supplies.

The peak current drawn by a typical cordless drill when stalled is at least 20A and can be much more than that.

## Query about BCD switches

I am building the UHF Remote Controlled Mains switch published in the February 2008 issue. I am having a problem placing a part on the board. The instructions say to install two PC-mount 6.4mm spade terminals immediately to the right of relay RLY1. Can you please tell me the catalog number in the Jaycar catalog, as their store staff could not find the component?

Secondly, I only have one 16-position BCD switch (time period selection) instead of the three actually needed. What does this mean to the project? (R. M., via email).

● For some reason, Jaycar don't stock PCB-mount spade connectors. You can get them from Altronics (Cat. H2094) or element14 (Cat. 4215618 or 421561802).

Alternatively, you could solder the wires to PCB pins but in that case it would be a good idea to provide some strain relief, eg, flow neutral-cure silicone sealant or hot-melt glue over the assembly after soldering.

Regarding the 16-position switches for the receiver module, you need one of those but you also need two 10-position switches. The transmitter needs one of each. If you don't want to fit switches, you can use wire links instead but then the transmitter/receiver identity could not be changed in future and the timer setting would also be fixed. You'd need to work out which links to set to provide the correct binary code for the settings required.

## Wants alternative to BASIC language

The Micromite projects that your team have developed look absolutely amazing. What has stopped me from building them is the use of BASIC to program the microcontroller. I grew up with Microbees in the 1980s and quite


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## Ask SILICON CHIP

. . . continued from page 102

honestly, I'm looking for something a little more sophisticated. Is there a Dev environment for the PIC that uses, for example, C? Would you recommend one that wasn't BASIC? (T. B. Belconnen, ACT).

● We asked the designer, Geoff Graham, to reply: If you are looking for a C programming environment for the PIC, you cannot beat the Microchip MPLAB X Integrated Development Environment and their XC series of compilers. They are full-functioned and there are free versions available.

However, be warned. Programming in the C language can be complex and difficult – that is why we developed MMBasic which is much easier to use.

## Reducing the gain of the headphone amplifier

Is there a way to make the 2005 Studio Series Headphone Amplifier have zero gain? I love running it with the SILICON CHIP valve preamp however there is simply too much gain and volume.

Still on the subject of valves, is there any chance a valve headphone amplifier will be published? As much as I'd like to try the Currawong I simply can't afford the kit cost even though it's cheap for a valve amplifier; $700 is simply too much for me (R. K., via email).

● You can reduce the gain of the No-

continued page 104

## Serviceman's Log – *continued from p43*

leads one to expect uncouth, misleading behaviour from resistors so I replaced it anyway.

Much to my disgust, the fault still remained! As a result, I now decided to remove the entire PCB assembly and examine it for bad solder joints and poor wiring connections etc.

This assembly actually consists of three separate PCBs: the main amplifier assembly PCB, a valve base circuit PCB assembly and an output socket PCB assembly. All three are connected by wiring and in particular, the valve base PCB assembly has five heavy-duty flat ribbon cables connecting it to the main PCB assembly.

I made a thorough inspection of these assemblies using a magnifying lamp but could find no sign of bad solder joints or poor wiring connections. This was really starting to puzzle me by now, so I reassembled the amplifier, carefully fitted all the valves, reconnected my audio oscillator and tried the amplifier out once more, this time wiggling the valves as it warmed up. And lo and behold, there was life in the old beast yet! When I wiggled V1, the output appeared and disappeared, depending on which way the valve was pushed.

Encouraged by this, I dismantled it again and looked even more closely at the valve base PCB assembly, especially around V1. And while I wasn't completely sure, it appeared that the valve sockets pins were a little too "open". As a result, I tightened them on all the valve bases, then reassembled the amplifier yet again and this time it worked perfectly!

This exercise was a valuable lesson re-learnt – there are more resistors in any circuit than meets the eye. Junction resistance can be a real problem in electronic circuits, so don't forget to look at connectors, plugs and sockets, and so on. SC

## Ask SILICON CHIP

*. . . continued from page 103*

vember 2005 headphone amplifier to unity by omitting resistor R2. However, the problem is really that the valve preamp provides too much signal. We assume you are using the February 2004 circuit? If so, you can make the volume control work more progressively by connecting a 100kΩ resistor in series with the 50kΩ potentiometer.

A valve headphone amplifier is not really practical. Your approach works well anyway and will have authentic valve sound.

## WiFi interference to headphone amplifier

I assembled an Altronics kit for the Portable Headphone Amplifier (SILICON CHIP, April 2011). It works really well except that during quiet music or in between tracks a motor-boating noise can be heard. I switched off my WiFi modem/router and the noise disappears (the response from the rest of the family is not so quiet!)

So I moved the amplifier as far as I could from the modem. This reduced the motor-boating but not completely. If I hold my hand over the amplifier the noise also stops. My main use is playing music from my desktop PC so I cannot separate the amplifier from the Wifi by more than 2m.

Can I shield the unit or add any filter capacitors etc, or would earthing help? (M. D., Paynesville, Vic).

- The headphone amplifier already has input filtering so if you cannot keep the unit more than 2m away from the Wifi modem, the only answer is shielding. Ideally, the unit should go in a small metal case but you might like to try using a small piece of copper laminate underneath the PCB. Place it so that the copper side is away from the PCB (to avoid shorts) and connect the copper to the earth of CON1.

In fact, we found that simply placing the headphone amplifier case on a sheet of aluminium or copper laminate is quite effective in eliminating this sort of noise.

## Dog visits to letter box not welcome

Have you ever done something to scare dogs away from the front path? I always have dogs coming along and doing their business just outside my letter-box, so I was thinking of something remote-controlled inside the letter box that would go off when I press a button from inside my place.

- We published a Barking Dog Blaster in September 2012 and a remote control for it in October 2012. Altronics sell the blaster (but not the UHF remote control part) as a kit K4500 (www.altronics.com.au). However, this may not work as a deterrent to a casual approach by a dog for a pit stop.

We have heard that an electric fence placed around the letter-box post and only activated for a short period during the "event" can quickly deter a dog. However, the risk of electric shock to passers-by is a definite possibility which could have legal consequences.

A better approach may be to try a natural dog repellent based on chilli, capsicum or ammonia. SC


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